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Effects of wastewater discharges on periphyton growth in Lake Mead, Nevada-Arizona

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EFFECTS OF WASTEWATER DISCHARGES ON PERIPHYTON GROWTH IN LAKE MEAD, NEVADA-ARIZONA

By

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ABSTRACT

A study of the effects of secondary-treated wastewater on periphyton growth in Lake Mead, Nevada-Arizona was conducted from September 1979 to December 1980. Periphyton ash-free dry weight, chlorophyll-a, dominant species composition, and alkaline phosphatase activity were measured on fiberglass substrates. Substrates were incubated for two to four weeks in littoral and limnetic habitats. Physical and chemical variables and phytoplankton chlorophyll-a were measured concurrently.

Transparency increased with increasing distance from the discharge. Secchi depth ranged from 0.75 m at the discharge confluence (station 2) in August, to greater than 20 m at the most distant stations (stations 9 and 10) in spring. Ortho-phosphorus (PO_4-P) and ammonia-nitrogen (NH_3-N) concentrations also followed this trend. Average PO_4-P concentrations were 37 µg/l at station 2 and 1-2 µg/l at stations 9 and 10. Ammonia-nitrogen concentrations averaged 84 µg/l at station 2 and 3 µg/l at the distant stations. Nitrite and nitrate-nitrogen concentrations were higher at the stations distant from the discharge because of the influence of the Colorado River inflow. Phytoplankton standing crop, estimated by chlorophyll-a, averaged 30 µg/l at station 2 and reached a maximum concentration (105 µg/l) in summer. Phytoplankton standing crops decreased with increasing distance from the discharge.

Periphyton production in Lake Mead followed the same spatial trend as PO_4-P, NH_3-N, and phytoplankton standing crop. The highest production was measured at station 2, near the discharge, and the lowest was measured at station 9. Light was found to be the primary factor and nitrogen the secondary factor controlling periphyton growth at station 2.

Nutrient concentrations are reduced by phytoplankton uptake and dilution as the inflow moves toward Hoover Dam. Periphyton and phytoplankton production was reduced accordingly. Nitrogen was the most likely factor limiting periphyton growth at station 5. Nitrogen and phosphorus were alternately limiting to growth at station 8. With seasonal N:P ratios greater than 100, phosphorus was certainly a limiting growth factor at stations 9 and 10 in the upper lake basin.

Phosphorus reduction by advanced wastewater treatment is being implemented to reduce phytoplankton productivity in Las Vegas Bay, Lake Mead. If light is limiting periphyton in Las Vegas Bay as evidence suggests, and there is shading of periphyton by phytoplankton, reduction in phytoplankton could result in an increase in periphyton.

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INTRODUCTION

Research Problem

High phytoplankton productivity in Las Vegas Bay, Lake Mead caused concern for water quality during the late 1960's (FWPCA 1967, Hoffman et al. 1967, EPA 1971). Early studies concluded that Las Vegas Wash discharges of secondary-treated sewage effluents were responsible for undesirable algal growth in the bay. EPA (1971) determined that Federal-State water quality standards were being violated.

Clark County is currently constructing a 90 mgd Advanced Wastewater Treatment Plant (AWT) to meet a 0.5 mg P/l standard adopted for Las Vegas Wash by the Nevada Environmental Commission in 1973. The secondary treatment plants now in operation have reduced the phosphorus concentration of their effluents to 1 mg/l using alum flocculation. Controversy regarding the need for the 0.5 mg/l standard arose because of apparent improvement in Las Vegas Bay water quality from 1968 to 1978. The average chlorophyll-a concentration in Las Vegas Bay in 1968 was 35 µg/l with a maximum value greater than 80 µg/l (Paulson 1981). Chlorophyll-a had decreased to an average of less than 10 µg/l in 1978 with a maximum concentration of 25 µg/l. In 1979 chlorophyll-a concentrations began to increase again. The average value for 1980 was approximately 30 µg/l. The highest concentration ever recorded (140 µg/l) occurred in summer 1982. This increasing trend can be related to

increased ammonia loading from Las Vegas Wash (Dr. L.J. Paulson, personal communication). Phosphorus loadings have not increased above 1978 levels.

This controversy primarily revolved around effects of nutrients on phytoplankton growth, but there were also complaints about periphyton growth on beaches and boat hulls. The purpose of this study was to determine effects of Las Vegas Wash discharges on the periphyton community in Lake Mead. Periphyton has been widely used to monitor water quality in rivers because the organisms are immobile and thus reflect local environmental conditions (Butcher 1932, Weber and Raschke 1970, Patrick 1973, Lowe 1974, Cooper and Wilhm 1975). In contrast to phytoplankton in lakes, little is known about critical concentrations of nutrients controlling growth rates or standing crops of periphyton (Brown and Austin 1973, Welch 1980). Periphyton and phytoplankton growth peaks within a system are often out of phase (Jorgensen 1957, Wetzel 1964), indicating differential utilization of resources. This study examined periphyton productivity in relation to physical and chemical factors and to phytoplankton standing crop in Lake Mead.

Studies of Periphyton Growth Factors

The literal translation of periphyton is "around plants", however, the term is frequently-used to describe the closely associated algae, protozoa, bacteria, rotifers, and other microorganisms living associated with or attached to a solid surface. Aufwuchs is a more appropriate term for this intricate community (Wetzel 1975), restricting the use of periphyton to the algae community attached to submerged materials

(Wetzel and Westlake 1969). Periphyton is often the most important primary producer group in lotic environments (Cooper and Wilhm 1975, Cattaneo et al. 1975) and contributes various portions of the production in lentic systems, depending upon the extent of the littoral zone and other factors. Wetzel (1975) cites examples in which periphyton production ranged from 1% of total production in an oligotrophic lake to 62% in a shallow, rapidly flushed lake.

Many factors can influence the periphyton community including light, substrate, water movement, pH, alkalinity, nutrients, metals, temperature, salinity, oxygen, and carbon dioxide (Weitzel 1979), but most research has dealt only with physical factors. McIntire and Phinney (1965) conducted research on periphyton grown in laboratory streams and found an almost linear relationship between light intensity and gross production until saturation intensity was reached between 1000-2000 ft-candles. They observed physiological and species compositional shifts in response to changing light intensities, and differences were observed between light-adapted and shade-adapted communities. Lowe and Gale (1980) examined algae communities colonizing slate, acrylic, smooth glass, and frosted glass in the Susquehanna River. They found a range in percent similarity between each artificial substrate and river stone of 60 - 78%, the greatest similarity occurred with the slate. Patrick (1973) found that glass slides sampled the natural diatom community with the exception of rare species. Reisen and Spencer (1970) examined diatom colonization of glass slides as a function of current velocity. They found an inverse relationship during initial stages of colonization and a positive correlation over the long term. Pfeifer and McDiffett (1975)

found currents enhanced photosynthesis in laboratory experiments. Whitford and Schumacher (1963) and Johnson et al. (1975) discuss temperature effects on species distributions. In general, Chrysophyceae have a low temperature requirement (below 15 °C). Most Bacillariophyceae and Chlorophyceae grow best between 15 °C and 20 °C. Cyanophyceae do well in high temperatures above 20 °C. There are numerous exceptions to these generalizations, especially within the Bacillariophyceae which has cold stenothermic, warm stenothermic, and eurythermic species.

Periphyton Productivity Methods

The periphyton community is heterogenously distributed and grows in highly variable microhabitats. Consequently, it is difficult to sample and researchers have attempted to standardize the physical environment and make quantitative analyses of this community using a variety of artificial substrates (eg. cement, styrofoam, plexiglass, glass, ceramic tile, wood, etc.). Glass slides have been the most widely used substrates because of their uniformity and availability (Hentschel 1916 as described in Collins and Weber 1978, Newcombe 1950, Patrick et al. 1954, Sladecek and Sladeckova 1964, Cattaneo et al. 1975). Although Patrick (1973) found that slides accurately reproduced the natural diatom community, Castenholz (1960) found that some filamentous green and blue-green algae did not readily colonize the smooth glass surface.

There are several methods of measuring periphyton productivity, but biomass accumulation rate has been the most widely used technique (Newcombe 1949, Castenholz 1960, Stockner and Armstrong 1971, Tilley and Haushild 1975). Biomass measurements represent net production (Wetzel

1965) resulting from gross production minus losses by respiration, consumption, predation, death, and decomposition (Sladecek and Sladeckova 1964). A change in biomass over time is one method of measuring productivity (Ryther 1956); Young (1945) first applied it to studies of periphyton growth on Scirpus in Douglas Lake, Michigan (Sladecek and Sladeckova 1964). When a clean substrate is placed in the water, accumulation is a result of colonization, cell growth, and reproduction. Because accumulation is slow during the colonization phase, biomass accumulation may represent low productivity estimates of a well-established periphyton community (Cooper and Wilhm 1975). Productivity is determined by:

$$P = \frac{mg\ AFDW}{T\ A}$$

where productivity (P) equals mg of ash free dry weight (AFDW) of periphyton expressed over the product of time (T) and area (A). Although biomass accumulation on artificial substrates may not be an accurate measurement of natural periphyton community productivity, it allows for comparison of different locations in the lake under more standardized conditions than would otherwise be possible.

Chlorophyll-a determinations are also used to estimate productivity and standing crop of periphyton. This assumes that the rate of photosynthesis is a function of chlorophyll-a content. McConnell and Sigler (1959) point out that the use of chlorophyll-a to estimate plant biomass is subject to errors caused by variation in the chlorophyll to dry weight ratio (0.09 to 2.00% of dry weight depending on the species of periphyton). Analyses can be seriously impaired by chlorophyll degradation products and appropriate corrections must be included in the

analyses (Wetzel 1963, McIntire and Phinney 1965).

Oxygen evolution can be used as an estimate of primary productivity using the light- and dark-bottle method. This method is best suited for eutrophic water where production is in the range of 3-200 mg $C \cdot m^{-2} \cdot h^{-1}$ during the light period (Slack 1973). An advantage of the light- and dark-bottle method is that it provides a measure of both gross and net productivity. Respiration is expressed for the whole community. Bottle effects can create problems for accurate determinations of natural productivity rates in both lentic and lotic environments. Enclosing water in a bottle affects turbulence which in turn affects nutrient availability. The closed system may also increase oxygen tension. If the incubation period is too long, there may be bacterial growth on the bottle surface causing the measurements to be invalid (Goldman 1968).

The utilization of carbon dioxide during photosynthesis can be measured by pH changes in the water or by carbon-14 uptake. Carbon dioxide uptake can be measured by recording pH changes and converting the changes to CO_2 concentrations (Verduin 1956). This method is not applicable in well buffered systems and it is difficult to measure periphyton productivity specifically with this method.

Periphyton productivity can be measured <u>in situ</u> with carbon-14 uptake in specially designed chambers (Loeb 1981). In lotic environments this method must utilize chambers with forced circulation for accurate measurements. The chamber is innoculated with labeled sodium carbonate ($Na_2{}^{14}CO_3$) and the sample is allowed to incubate approximately one-half the light period. The sample is then removed and analyzed (refer to

Wetzel 1963 and APHA 1981 for detailed methods). Carbon-14 is more sensitive than oxygen and carbon dioxide measurement techniques, however, it is not known whether carbon-14 measures gross productivity, net productivity, or something inbetween (Goldman 1968).

METHODS

Study Area

Lake Mead is a reservoir on the Colorado River. It was formed in 1935 by the construction of Hoover Dam, 15 km northeast of Las Vegas, Nevada. It is the second in a series of four main stem reservoirs on the Colorado River, including Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu. Lake Mead has the largest volume of any reservoir in the U.S., and is second in surface area only to Lake Powell. It is located in the arid Mojave Desert region with an average annual precipitation less than 12.7 cm (Hoffman and Jonez 1973). A summary of the physical description of the reservoir is presented in Table 1.

Lake Mead has two major basins, Virgin Basin and Boulder Basin, connected by a narrow canyon (Fig. 1). The major inflow to Lake Mead is from the Colorado River on the east end of the reservoir with lesser inflows from the Virgin and Muddy Rivers into Overton Arm, and from Las Vegas Wash into Las Vegas Bay.

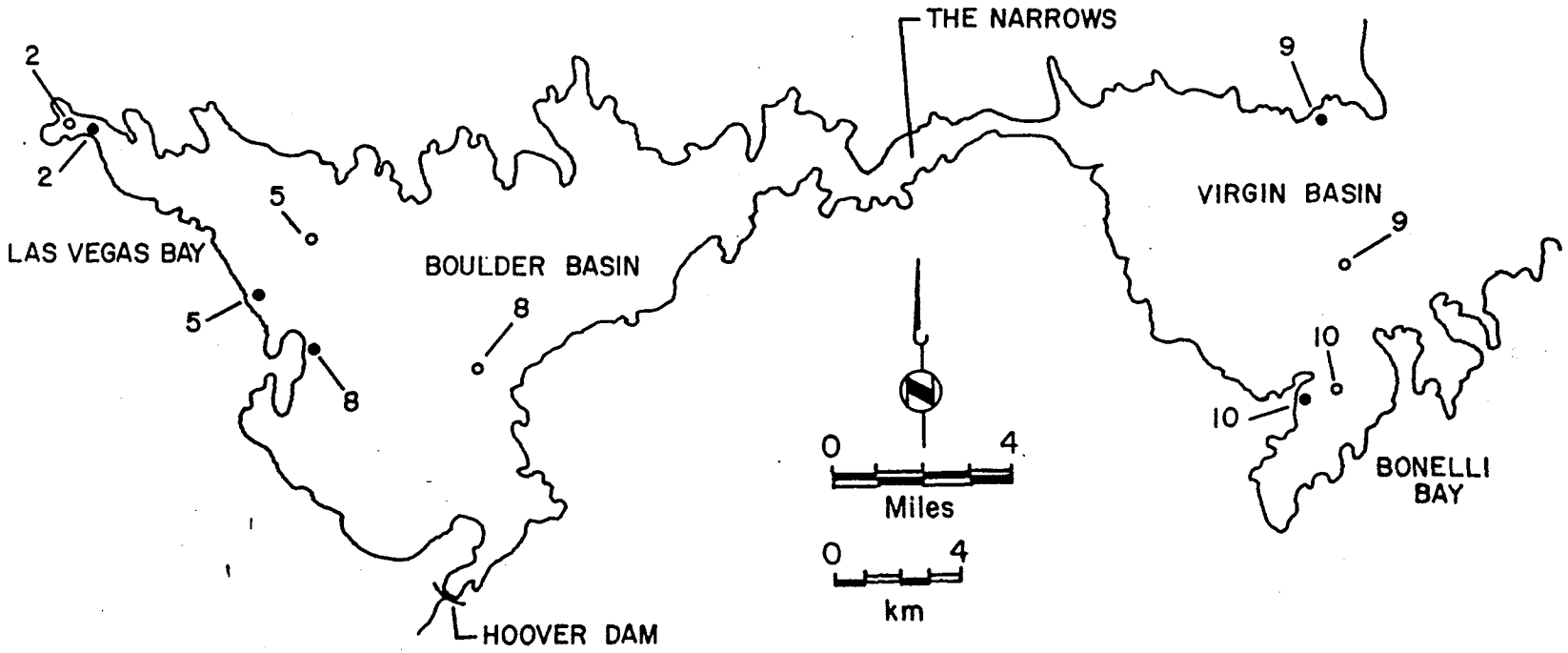
Las Vegas Wash was historically an intermittant stream, but perennial flows developed due to discharges of secondary-treated sewage and industrial effluents. Las Vegas Wash contributes less than 1% of the total annual discharge at Hoover Dam (Goldman and Deacon 1978), but it provides 60% of the phosphorus input (Paulson et al. 1980). In contrast, 85% of the inorganic nitrogen input is derived from the Colorado River

Table 1. Morphometry of Lake Mead, Nevada-Arizona

Maximum depth (m)	180
Mean depth (m)	55
Surface area (km^2)	660
Volume ($m^3 \times 10^9$)	36
Maximum length (km)	183
Maximum width (km)	28
Shoreline development	9.7
Approximate storage (yr)	4

Source: Paulson et al. 1980

Figure 1. Map of Lake Mead showing periphyton sampling stations. Open circles are limnetic stations; solid circles are littoral stations.



MAP OF LAKE MEAD

(Paulson et al. 1980). Nitrogen and phosphorus loadings to Lake Mead from Colorado River and Las Vegas Wash for the period from October 1977 through September 1978 are presented in Table 2. Recent studies have shown that the upper basin is phosphorus deficient and Las Vegas Bay and parts of Boulder Basin are nitrogen limited during summer (Paulson and Baker 1980).

Sampling Stations and Frequency

Periphyton was collected at five limnetic and five littoral stations in Lake Mead (Fig. 1). Stations 2 and 5 in Las Vegas Bay and station 8 in Boulder Basin were located along a transect from the wastewater discharge point of Las Vegas Wash. Station 9 in Virgin Basin and station 10 in Bonelli Bay represent reference stations, unaffected by the wastewater discharges. Bonelli Bay is similar in morphometry to Las Vegas Bay, but Detrital Wash, which enters the southern end of the bay, flows only during storms.

Depth, aspect, and natural substrates are presented in Table 3 for each sampling station. Littoral station 10 was initially located due west of the limnetic station on a gypsum deposit. It was moved to the west shore of a small island, north of the limnetic station, in April 1980, when a storm caused the gypsum slabs to slough into the bay.

Limnetic samplers were used in an attempt to control variables associated with littoral stations, such as substrate, shading, and siltation. This allowed for better isolation of effects of chemical and physical characteristics of the water body on the periphyton community.

Table 2. Nutrient loadings to Lake Mead, October 1977 through September 1978.

NUTRIENT (kg/yr)	LOADING	
	Colorado River	Las Vegas Wash
NO_3-N x 10^5	45.63	3.49
NH_3-N x 10^5	1.42	3.24
Total inorganic N x 10^5	47.05	6.73
PO_4-P x 10^3	56.80	136.60
Total-P x 10^3	198.70	263.10
N:P	83	5

Source: Paulson and Baker 1980

Table 3. Lake Mead sampling station characteristics.

	LIMNETIC	LITTORAL	
STATION	Depth*	Aspect	Natural Substrate
2	12 m	NE	boulders
5	47 m	E	mixed silt, gravel, gypsum
8	142 m	E	rock
9	135 m	S	mixed gravel, sand, silt
10	43 m	SW	gypsum

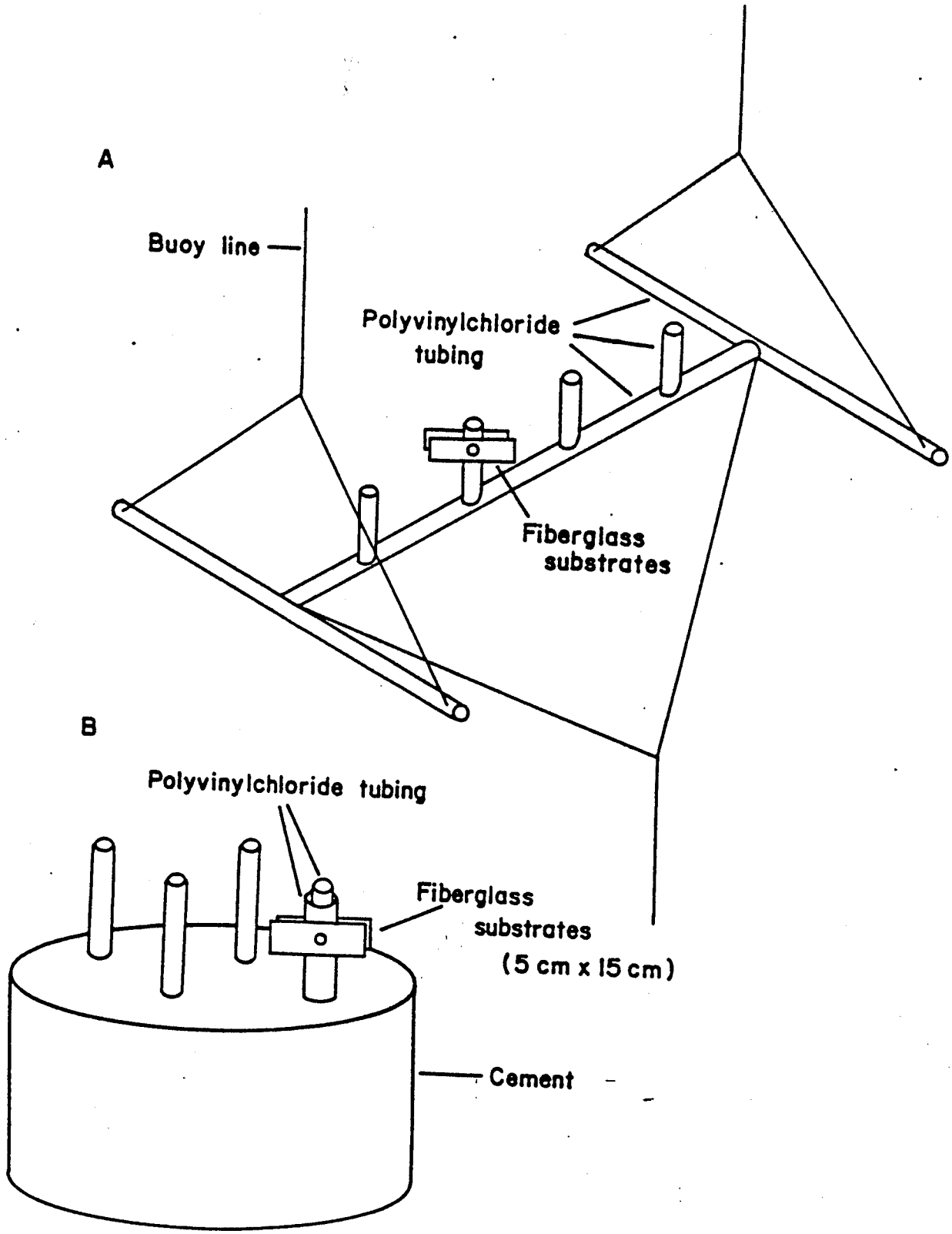
*at lake elevation of 366 m above sea level

Sampling was conducted for 16 months from September 1979 to the beginning of December 1980. Artificial substrates were collected approximately every two weeks with the exception of the period from November 1979 through February 1980 when they were collected monthly. Due to problems associated with sampler design, the first collection of samples from limnetic stations 5, 8, and 9 was delayed until December 1979. Littoral station 9 was not established until April 1980.

Substrates, Incubation, and Collection Procedures

Fiberglass samplers were used as substrate because boat hulls are the most common site of nuisance periphyton growth in Lake Mead. Periphyton was collected on 5 cm x 15 cm fiberglass rectangles, with two rectangles riveted to opposite sides of a polyvinylchloride (PVC) tube (Fig. 2). These tubes in turn slid onto upright PVC tubes of smaller diameter, holding the fiberglass substrates in a vertical position to reduce the effects of siltation. For littoral stations the smaller diameter support tubes were embedded in a cement slab which was placed on the sediment surface at 2 m depth at station 2 and 3 m depth at all other stations. The limnetic sampler support system consisted of an H-shaped PVC tube structure supported by two buoys holding the substrates at 2 m at station 2 and 3 m at the other stations. A cement anchor held each sampler system in place. After difficulties were encountered in relocating the limnetic sampler systems, a cross-line was installed connecting the sampler systems to permanent navigation buoys. For consistancy in light and temperature regimes the depth of all samplers was adjusted as lake level changed during the year.

Figure 2. In situ incubation apparatus for sampling periphyton growth in the limnetic (1A) and the littoral (1B) zones of Lake Mead.


A
Buoy line
Polyvinylchloride tubing
Fiberglass substrates
B
Polyvinylchloride tubing
Fiberglass substrates
(5 cm x 15 cm)
Cement

Substrates were collected by SCUBA divers and carefully brought to the surface. Sloughing of periphyton was a serious problem at times, but could not be reduced due to location of samplers in deep water. Clean, acid-rinsed substrates replaced collected samples. Substrates were placed upright in a frame in an ice-filled chest to keep them chilled and in the dark, and to prevent disruption of substrate surfaces. An atomizer filled with lake water was used to prevent dessication of the substrates. Duplicate substrate units were collected from each station on each sampling date.

Laboratory Methods

Dry and Ash-Free Dry Weight

Subsamples (25 or 50 cm^2) were collected from the fiberglass substrates with the edge of a glass slide and a rubber policeman and rinsed into numbered and tared aluminum weighing dishes. Weighing dishes were previously combusted at 550 °C for 1 h. The dish and sample were then dried to constant weight (24 h) at 105 °C (APHA 1981) and weighed to the nearest 0.1 mg to determine dry weight of the sample.

Dishes were then combusted in a muffle furnace at 550 °C for 1 h (Vollenweider 1969). The ash was rewetted with distilled water to reintroduce the water of hydration and dried to constant weight at 105 °C (24 h). Dishes were weighed to the nearest 0.1 mg. Total weight after drying minus the combusted weight was the AFDW, or organic content of the sample. Dry weight and AFDW were divided by the days of incubation and expressed as $mg \cdot m^{-2} \cdot d^{-1}$. Inorganic sedimentation was substantial at

times, consequently, AFDW rather than dry weight was used for productivity estimates.

Chlorophyll-a and Phaeophytin-a

Subsamples for chlorophyll-a and phaeophytin-a were collected in an identical manner to that for dry weight. Subsamples were rinsed onto Whatman GF/C glass fiber filters and filtered at 25 mm Hg to remove excess water. Filters were folded in half, placed in screw-capped glass centrifuge tubes, and frozen until analysis. Storage time was usually about two days and never more than one week.

The methanol extraction technique of Holm-Hansen and Riemann (1978) was chosen because it demonstrated that methanol had a better extraction efficiency and shorter extraction time than acetone and eliminated the need for sample homogenization. Samples were brought to room temperature in the dark. Ten milliliters of reagent grade methanol were added to each centrifuge tube with a volumetric pipet. Samples were then stored in the dark at room temperature during the 1 h extraction. The filtration step reported at this point in the procedure of Holm-Hansen and Riemann (1978) was replaced with a 10 min centrifugation to clear the solution.

An aliquot of the supernatant (3.2 ml) was transferred to a 1 cm pathlength cuvette. Absorption was read on a Coleman 55 spectrophotometer against a methanol blank at 750 nm and 665 nm before and after acidification with 105 µl of 0.1 N HCl. The neutralization step of Holm-Hansen and Riemann (1978) was deleted and compensated for by a correction factor which allows for the absorbance shift occurring

in phaeophytin-a at a given pH. Chlorophyll-a and phaeophytin-a were calculated using Tett's formulas (1975, 1977):

$$\text{Chl-a}(mg \cdot m^{-2} \cdot d^{-1}) = \frac{G}{1-GJ}\left[(E^U - E^A) - JGE^A(H - 1)\right] \frac{v}{V} / t$$

$$\text{Phaeo-a}(mg \cdot m^{-2} \cdot d^{-1}) = \frac{G}{1-GJ}(HE^A - E^U) \cdot \frac{v}{V} / t$$

where $G = 0.029\ cm \cdot mg \cdot ml^{-1}$

$J = 5.9\ ml \cdot cm^{-1} \cdot mg^{-1}$

$H = 2.0$

E = absorbance at 665 nm before acidification, corrected for background absorbance at 750 nm

E = absorbance at 665 nm after acidification, corrected for background absorbance at 750 nm

v = extraction volume (ml)

V = subsample area (m^2)

t = incubation time (d)

Note: G, J, and H are constants determined by Robert C. Furtek, USEPA, EMSL-LV, Las Vegas, Nevada using methods in Tett (1975).

Alkaline Phosphatase

Perry's (1972) sensitive fluorometric method as modified by Shapiro (University of Minnesota) was used for assay of alkaline phosphatase activity (APA). APA is measured as an increase in fluorescence as the substrate, 3-O-methylfluorescein phosphate, is hydrolyzed to the more fluorescent product, 3-O-methylfluorescein. Results are reported as nmoles PO_4 released per square meter per minute.

Upon return to the laboratory after field collection, a 2 cm

subsample was collected from one substrate unit of each limnetic station with a glass slide and rubber policeman. This subsample was dispersed in 100 ml of distilled water. A set of six test tubes (Bausch and Lomb Spectronic 20 colorimeter) was prepared for each station. Six milliliters of sample and 2 ml Tris buffer were pipeted into each tube. Shapiro's modification added 300 mg $MgCl_2$/l of buffer. Three tubes from each station were blanks; 1 ml EDTA was added to these. All tubes were then placed in a 25 °C water bath in the dark where they remained during analysis. A Turner 110 fluorometer with a 47B primary filter [Wratten gelatin filter (Kodak), cat. no. 149 5795] next to the lamp and a combination of 2A [Wratten gelatin filter (Kodak), cat. no. 164 4988] and 12 [Wratten gelatin filter (Kodak), cat. no. 149 5522] secondary filters near the photomultiplier tube was used for the analysis. One milliliter of substrate was added to each tube, and the fluorescence was read after thorough mixing of the sample. Blanks were read at 0 and 30 min; samples were read at 0, 15, and 30 min. After 30 min, 1 ml EDTA was added to the samples, they were mixed, and the fluorescence read again. A standard curve was calculated using dilutions of 3-O-methylfluorescein (Sigma M7004). Sample activity was determined after subtracting the average fluorescence of the three blanks. Detailed methods including preparation of standards and substrate are presented in Kellar et al. (1980).

Species Composition

Periphyton was scraped from the substrate with the edge of a glass slide and a rubber policeman and preserved in polyethylene bottles with Lugol's solution. Samples were stored in the dark until analysis.

A slide for diatom species identifications was prepared by placing several drops of the sample on a glass coverslip and evaporating it to dryness on a hot plate. The residue was then incinerated in a muffle furnace at 550 °C for 20 min and mounted in Hyrax on a glass slide. Identifications were made at 1000 magnification.

A wet mount was examined at 450 magnification in a Palmer-Maloney counting chamber, and the first 200 cells encountered were recorded. Cell volumes were calculated for dominant species by approximation of an appropriate geometric shape. The species were ranked by relative cell volume and the top five species were reported as the dominants. A species also had to represent at least 1% of the total cell volume to be considered dominant. If fewer than five species attained a minimum of 1% each of the cell volume at a station, then fewer than five species are reported for that date. When the community was comprised of tightly interwoven, filamentous forms that could not be dispersed, ranking of dominant taxa was visually estimated.

Chemical and Physical Measurements

Chemical and physical measurements referred to in this thesis and methods of determination are listed in Table 4. Measurements were performed by the staff of Lake Mead Limnological Research Center, Department of Biological Sciences, University of Nevada, Las Vegas using methods described in Kellar et al. (1980). Data presented are 0-5 m depth integrated values.

Table 4. Chemical and physical measurements and methods of determination.

PARAMETER	METHOD
temperature	Hydrolab
transparency	secchi disk
PO_4-P	modification of Strickland and Parsons (1972) and Goldman (1974)
NH_3-N	modification of Liddicoat et al. (1975)
NO_2+NO_3-N	modification of Kamphake et al. (1967)
phytoplankton chl-a	modification of Golterman (1969) and Strickland and Parsons (1972)

RESULTS

Seasonal and Spatial Variations in Physical Factors

Temperature

Spatial temperature variations in Lake Mead were minimal during the study, therefore, temperatures at station 2 are presented as representative of the lake (Fig. 3). Temperatures are an average of values from the surface to 5 m at 1 m intervals. A minimum temperature of 11.5 °C occurred in January and a high value of 30.5 °C was recorded in July. Destratification began to occur in September, and the reservoir was completely mixed by late December 1979. Thermal stratification developed in June 1980 with the thermocline at 10-15 m.

Transparency

Secchi depths recorded at the five stations during this 16 month study are presented in Fig. 4. Generally, greatest values were recorded in spring, then decreased through summer and fall, and increased again late in fall. Secchi depth increased with increasing distance from the Las Vegas Wash throughout the year. Values recorded in Bonelli Bay (station 10) were usually slightly less than in Virgin Basin (station 9). Measurements ranged from 0.75 m at station 2 in August to greater than 20 m at stations 8 and 9 during spring.

Figure 3. Temperatures (°C) at station 2 from September 1979 through November 1980. Values are averages from the surface to 5 m measured at 1 m intervals.

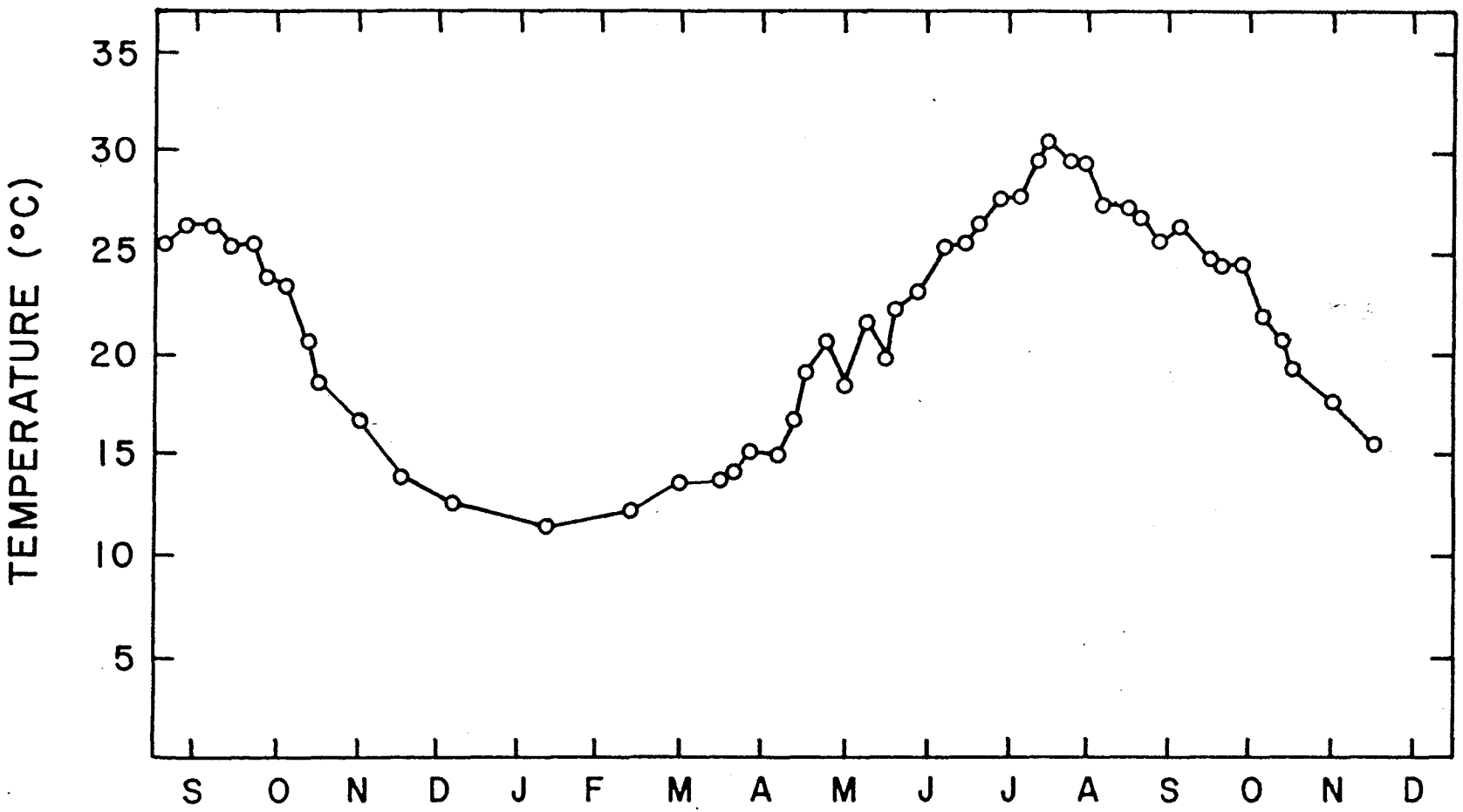
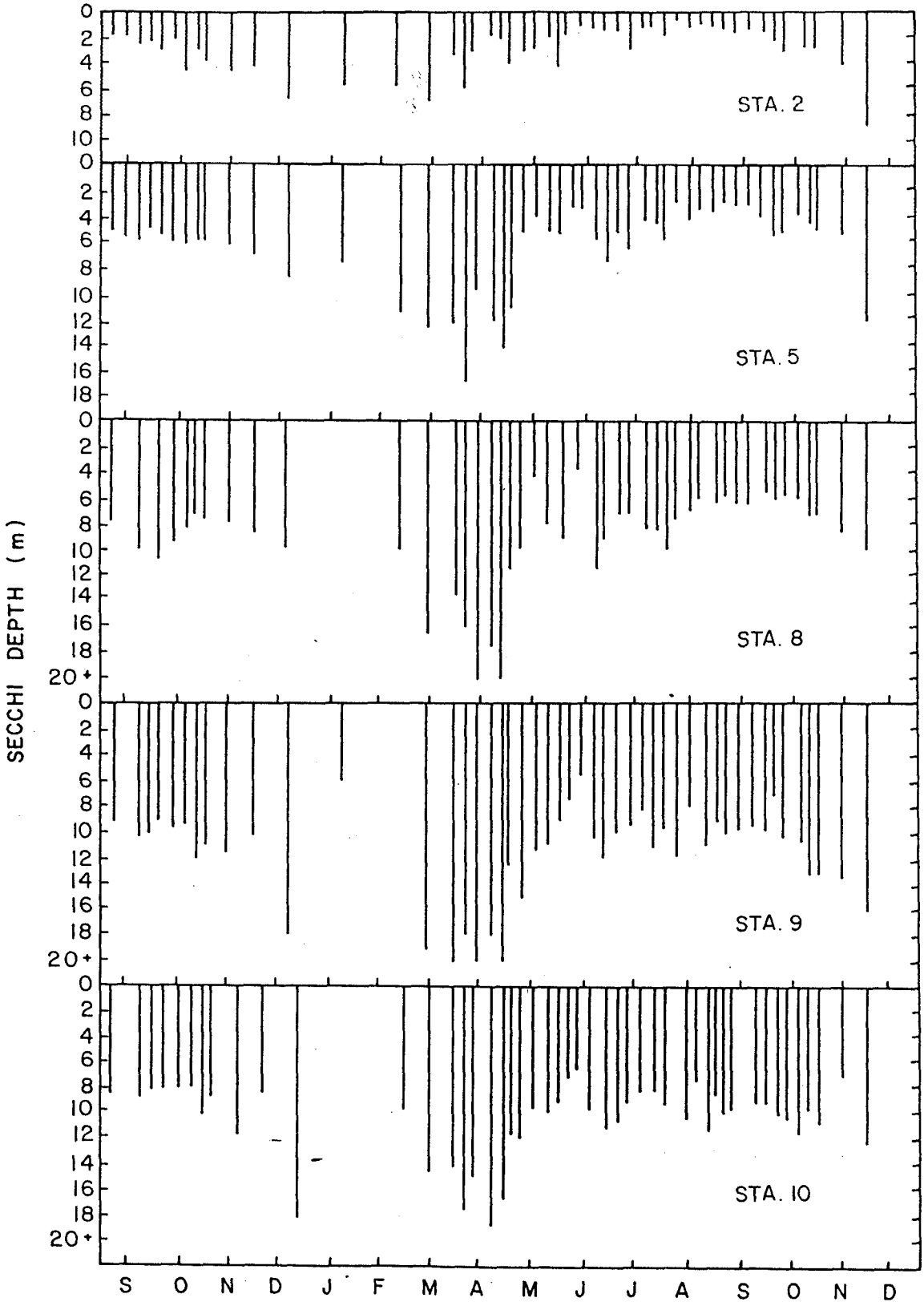

TEMPERATURE (°C)
35
30
25
20
15
10
5
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D

Figure 4. Secchi depths (m) at five stations from September 1979 through November 1980.


SECCHI DEPTH (m)
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10
0
2
4
6
8
10
12
14
16
18
20+
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D

Seasonal and Spatial Variations in Nutrients and Phytoplankton

Nutrients

Ortho-phosphorus

Ortho-phosphorus (PO_4-P) concentrations at station 2 were highly variable ranging from 4 to 312 µg/l, with the maximum occurring in February (Fig. 5). The average concentration was 37 ± 7 µg/l (S.E.) for the 16 month sampling period. Ortho-phosphorus concentrations at station 5 were less variable and averaged 6 ± 0.5 µg/l for the study period. Ortho-phosphorus concentrations at stations 8, 9, and 10 were similar and seasonal variations were minimal. Average PO_4-P concentrations were 1-2 µg/l and values less than 1 occurred during late summer and fall 1980 at these stations.

There was a trend of decreasing PO_4-P with increasing distance from the Las Vegas Wash (Fig. 8), and station 2 usually had concentrations that were an order of magnitude higher than other stations. This was due to high phosphorus loading from Las Vegas Wash.

Ammonia-nitrogen

Ammonia-nitrogen (NH_3-N) concentrations at station 2 were highly variable and ranged from 3 µg/l on May 14, to 472 µg/l just one week later (Fig. 6). This pulse was probably a result of wind induced mixing after the lake had begun to stratify. The average value for the study period at this station was 84 ± 15 µg/l. Ammonia-nitrogen concentrations at station 5 were lower and seasonal trends were more distinct than at

Figure 5. Ortho-phosphorus concentrations (µg/l) at five stations from September 1979 through 1980.

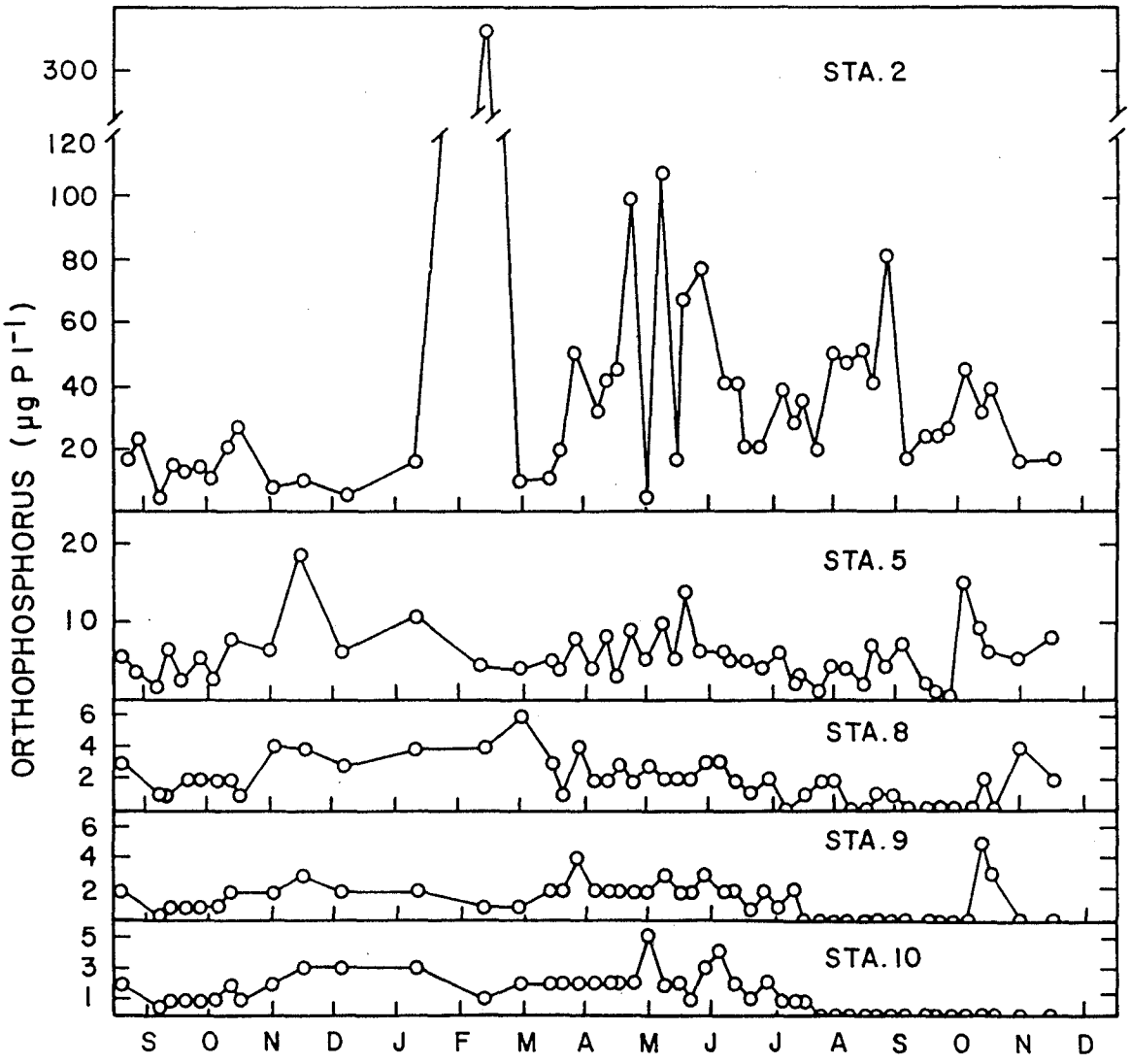
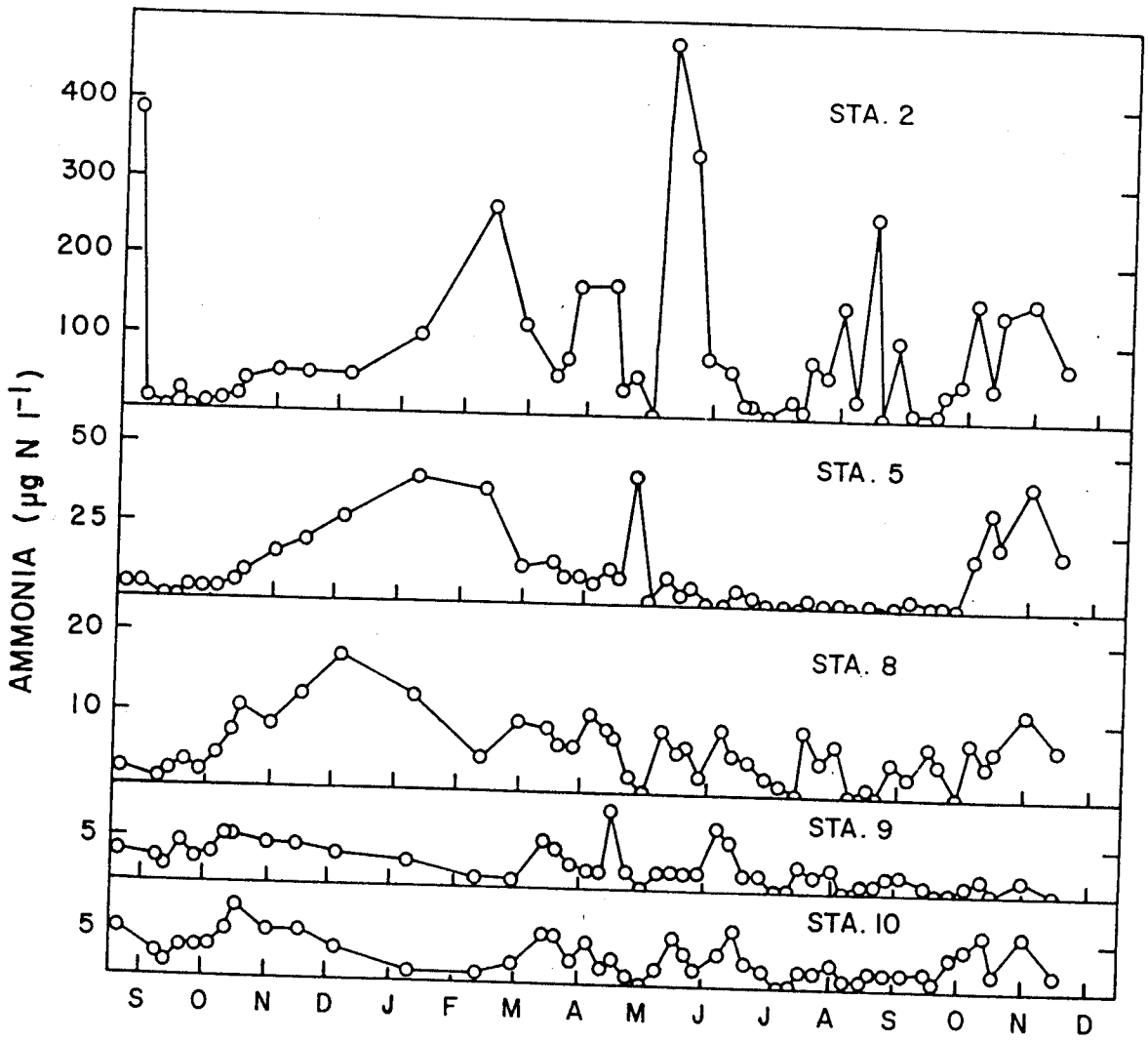

ORTHOPHOSPHORUS (µg P l⁻¹)
300
120
100
80
60
40
20
STA. 2
20
10
STA. 5
6
4
2
STA. 8
6
4
2
STA. 9
5
3
1
STA. 10
S O N D J F M A M J J A S O N D

Figure 6. Ammonia-nitrogen concentrations (µg/l) at five stations from September 1979 through November 1980.


AMMONIA (µg N l⁻¹)
400
300
200
100
50
25
20
10
5
5
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10
S O N D J F M A M J J A S O N D

station 2. The average concentration was 10 ± 2 µg/l with a gradual increase through the fall and winter. Ammonia-nitrogen concentrations decreased rather abruptly in spring as the lake stratified and phytoplankton productivity increased. Concentrations became very low (<3 µg/l) during summer and early fall months. The average NH_3-N concentration at station 8 was 5 ± 0.5 µg/l, also with highest levels occurring in late fall and winter months. Stations 9 and 10 both had average concentrations of 3 ± 0.3 µg/l, showing little seasonal variation. Ammonia-nitrogen concentrations also decreased with increasing distance from Las Vegas Wash (Fig. 8).

Nitrite and nitrate-nitrogen

Nitrite and nitrate-nitrogen (NO_2+NO_3-N), unlike the other nutrients, showed a distinct seasonal pattern. Concentrations progressively increased from late fall to spring, and then gradually decreased to low levels during summer and early fall (Fig. 7). The average NO_2+NO_3-N concentration at station 2 was 128 ± 15 µg/l. Station 5 had an average value of 74 ± 12 µg/l and an extended period of depletion during the summer. The average NO_2+NO_3-N concentration at station 8 was 84 ± 12 µg/l and depletion occurred in late summer and early fall. Concentrations recorded at stations 9 and 10 were highest and averaged 166 ± 18 µg/l and 144 ± 11 µg/l, respectively. Seasonal NO_2+NO_3-N concentrations are presented in Figure 8.

Phytoplankton

Phytoplankton standing crop, estimated by chlorophyll-a concentration, was highly variable at station 2 (Fig. 9). Standing crop

Figure 7. Nitrite and nitrate-nitrogen concentrations (µg/l) at five stations from September 1979 through November 1980.

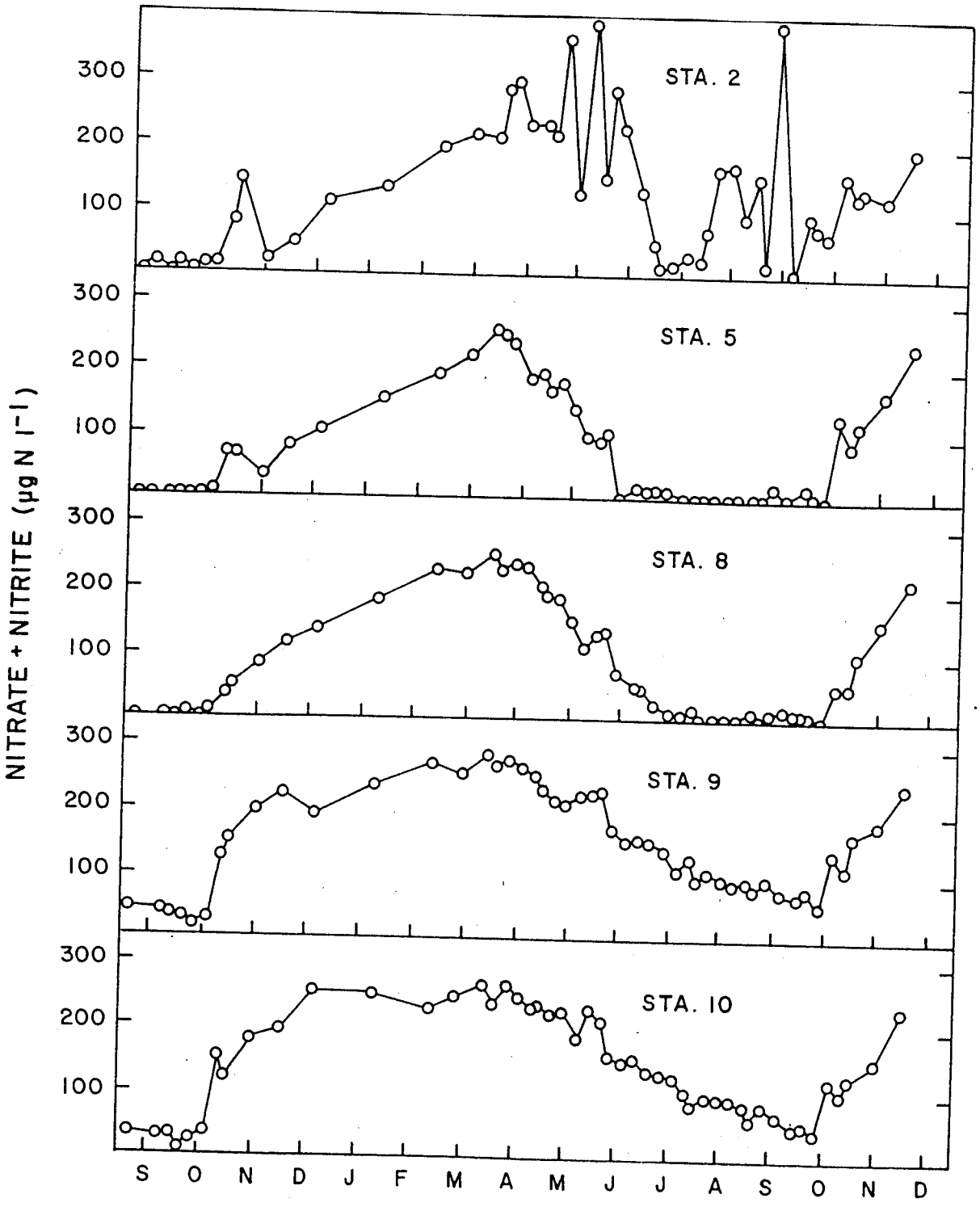
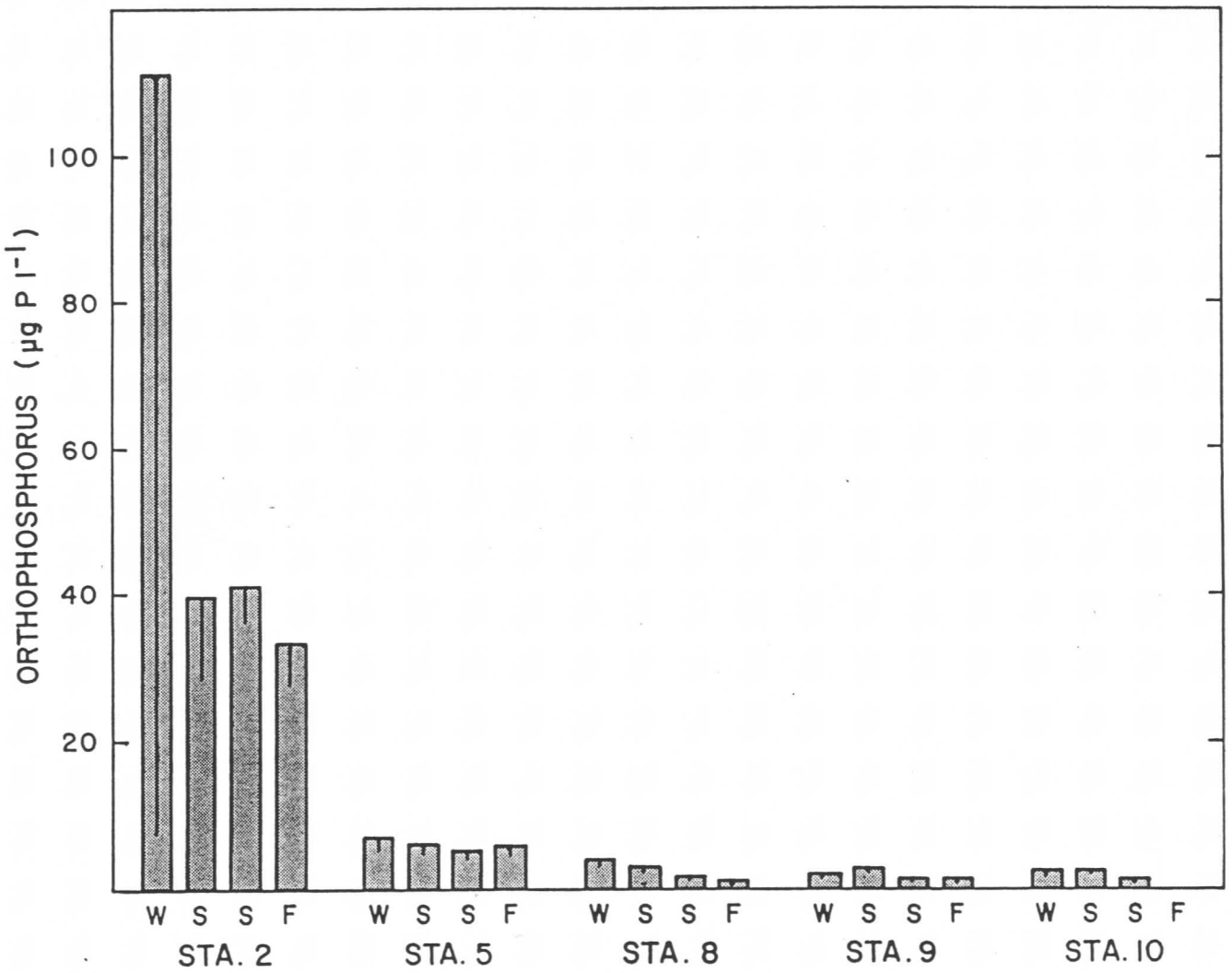
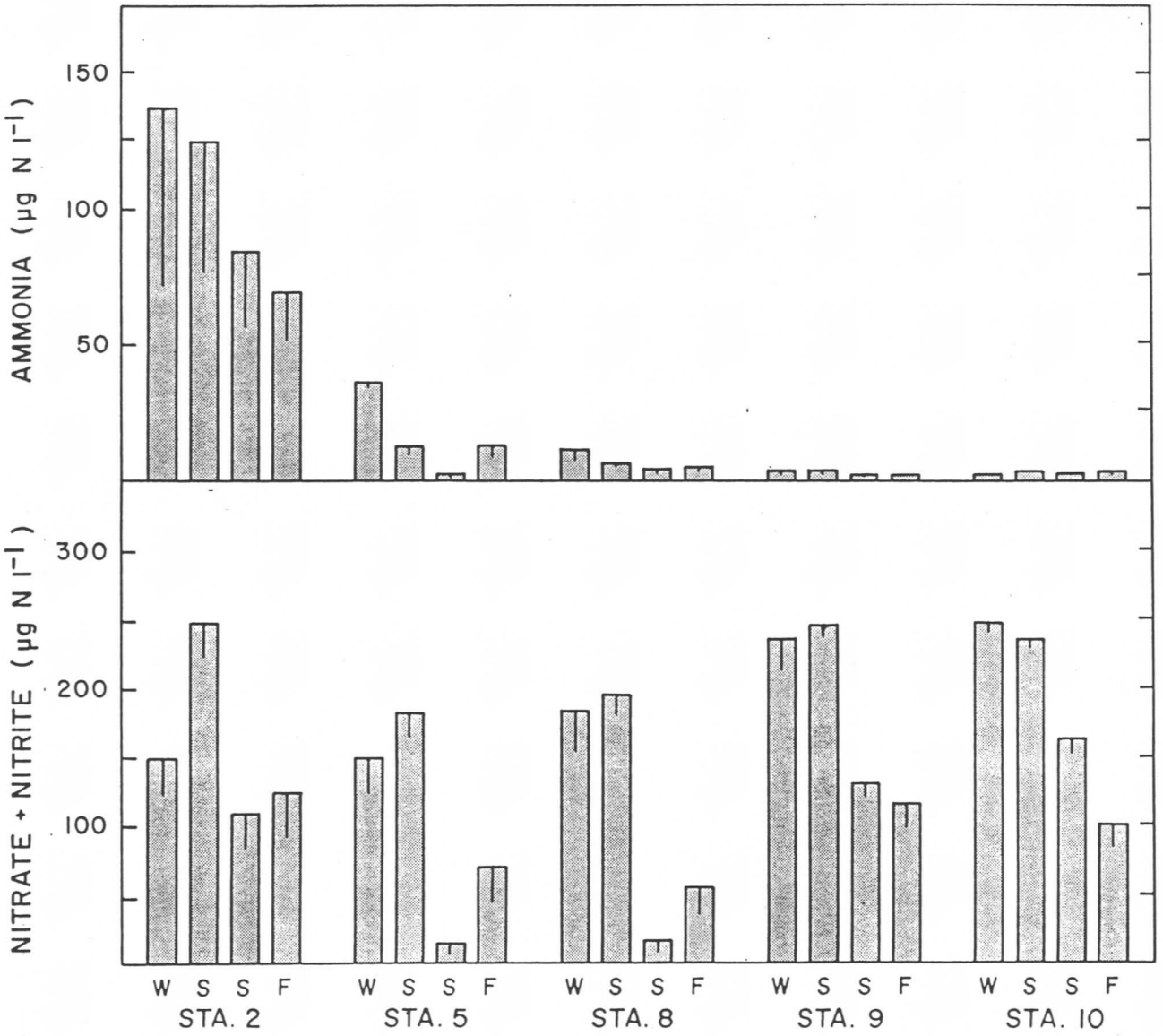

NITRATE + NITRITE (μg N l⁻¹)
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10
300
200
100
S O N D J F M A M J J A S O N D

Figure 8. Average seasonal nutrient concentrations (µg/l) at five stations from December 1979 through November 1980. Error bars are one standard error. ND is no data. W, S, S, and F under the bars correspond to winter, spring, summer, and fall, respectively.


ORTHOPHOSPHORUS (µg P l⁻¹)
100
80
60
40
20
W S S F
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10


AMMONIA (µg N l⁻¹)
150
100
50
NITRATE + NITRITE (µg N l⁻¹)
300
200
100
W S S F
STA. 2
W S S F
STA. 5
W S S F
STA. 8
W S S F
STA. 9
W S S F
STA. 10

began increasing in spring, reached a maximum value (105.2 µg/l) in summer, and decreased into fall. Minimum standing crop occurred in winter. Stations 5 and 8 were less variable, having maximum phytoplankton standing crops in fall (28.0 and 13.9 µg/l, respectively) (Fig. 10). Standing crops were low at stations 9 and 10 throughout the year (Fig. 11).

Phytoplankton chlorophyll-a concentrations were greatest at station 2 and decreased rapidly with increasing distance from Las Vegas Wash. Averages for the study period for stations 2, 5, 8, 9, and 10 were 29.5 ± 3.6 µg/l, 6.4 ± 0.9 µg/l, 2.9 ± 0.5 µg/l, 1.0 ± 0.1 µg/l, and 1.0 ± 0.1 µg/l, respectively.

Seasonal and Spatial Variations in Periphyton

Biomass Accumulation Rate

Periphyton productivity at limnetic station 2 was highly variable, but consistantly had the greatest productivity each season. Maximum growth of 1072 $mg \cdot m^{-2} \cdot d^{-1}$ occurred in May (Fig. 9). The next greatest productivity occurred at station 5 with the exception of station 8 during winter, resulting from a large population of Cymbella affinis. Productivity at station 5 was less variable than at station 2, but peaks of 554 and 821 $mg \cdot m^{-2} \cdot d^{-1}$ occurred in May and December 1980, respectively (Fig. 10). Except for winter, stations 8, 9, and 10 had similar patterns, and average seasonal productivities were less than 100 mg $AFDW \cdot m^{-2} \cdot d^{-1}$. Maximum productivity occurred at station 8 (295 $mg \cdot m^{-2} \cdot d^{-1}$) in December 1979 (Fig. 10). A second, lesser peak of

Figure 9. Phytoplankton chlorophyll-a concentrations ($\mu g/l$) and periphyton chlorophyll-a ($mg \cdot m^{-2} \cdot d^{-1}$) and ash-free dry weight ($mg \cdot m^{-2} \cdot d^{-1}$) accumulation rates at station 2. Open circles are the limnetic station and dark circles are the littoral station.

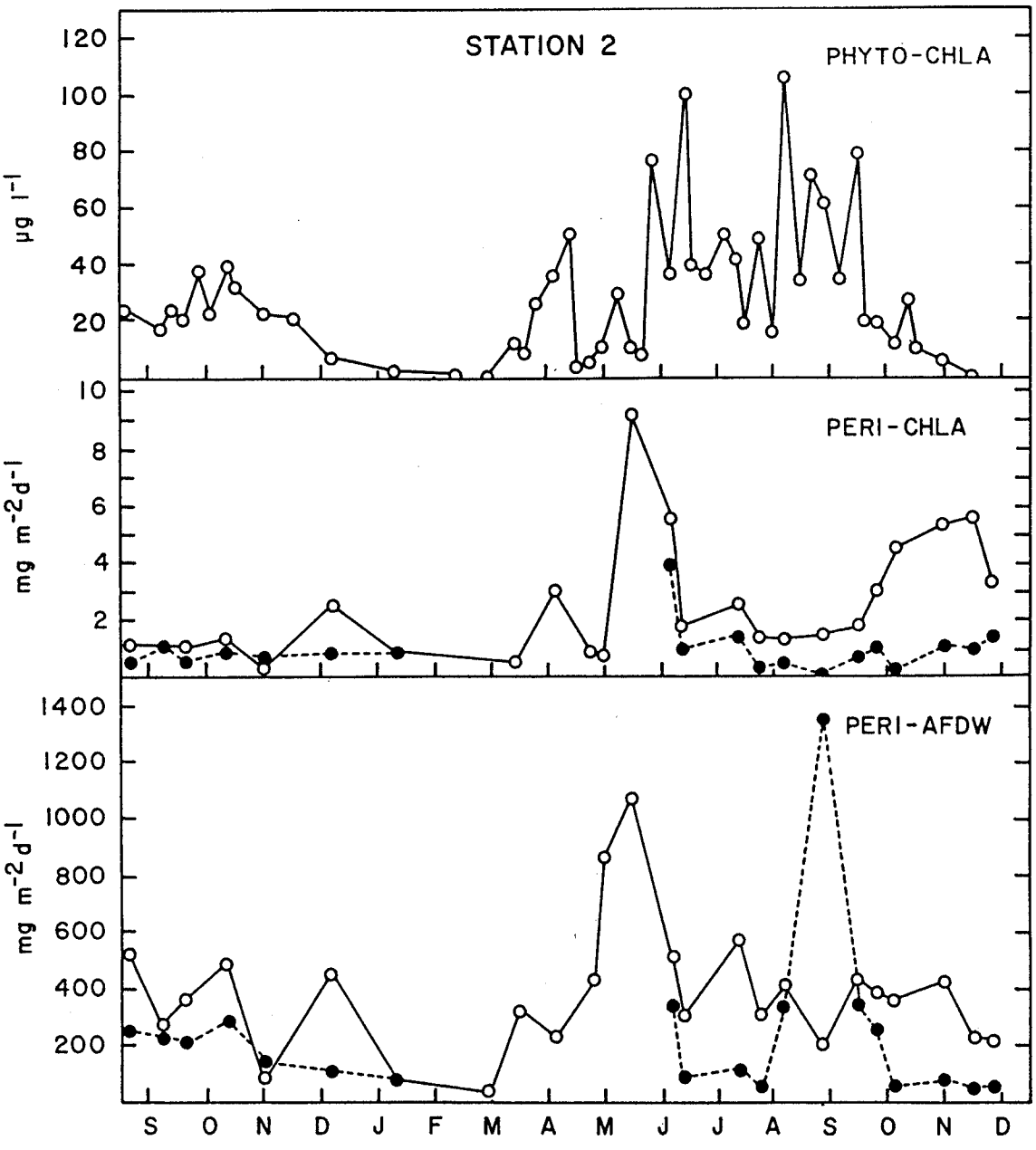

STATION 2
PHYTO-CHLA
PERI-CHLA
PERI-AFDW
µg l-1
mg m-2d-1
mg m-2d-1
120
100
80
60
40
20
10
8
6
4
2
1400
1200
1000
800
600
400
200
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D

Figure 10. Phytoplankton chlorophyll-a concentrations ($\mu g/l$) and periphyton chlorophyll-a ($mg \cdot m^{-2} \cdot d^{-1}$) and ash-free dry weight ($mg \cdot m^{-2} \cdot d^{-1}$) accumulation rates at stations 5 and 8. Open circles are the limnetic stations and dark circles are the littoral stations.

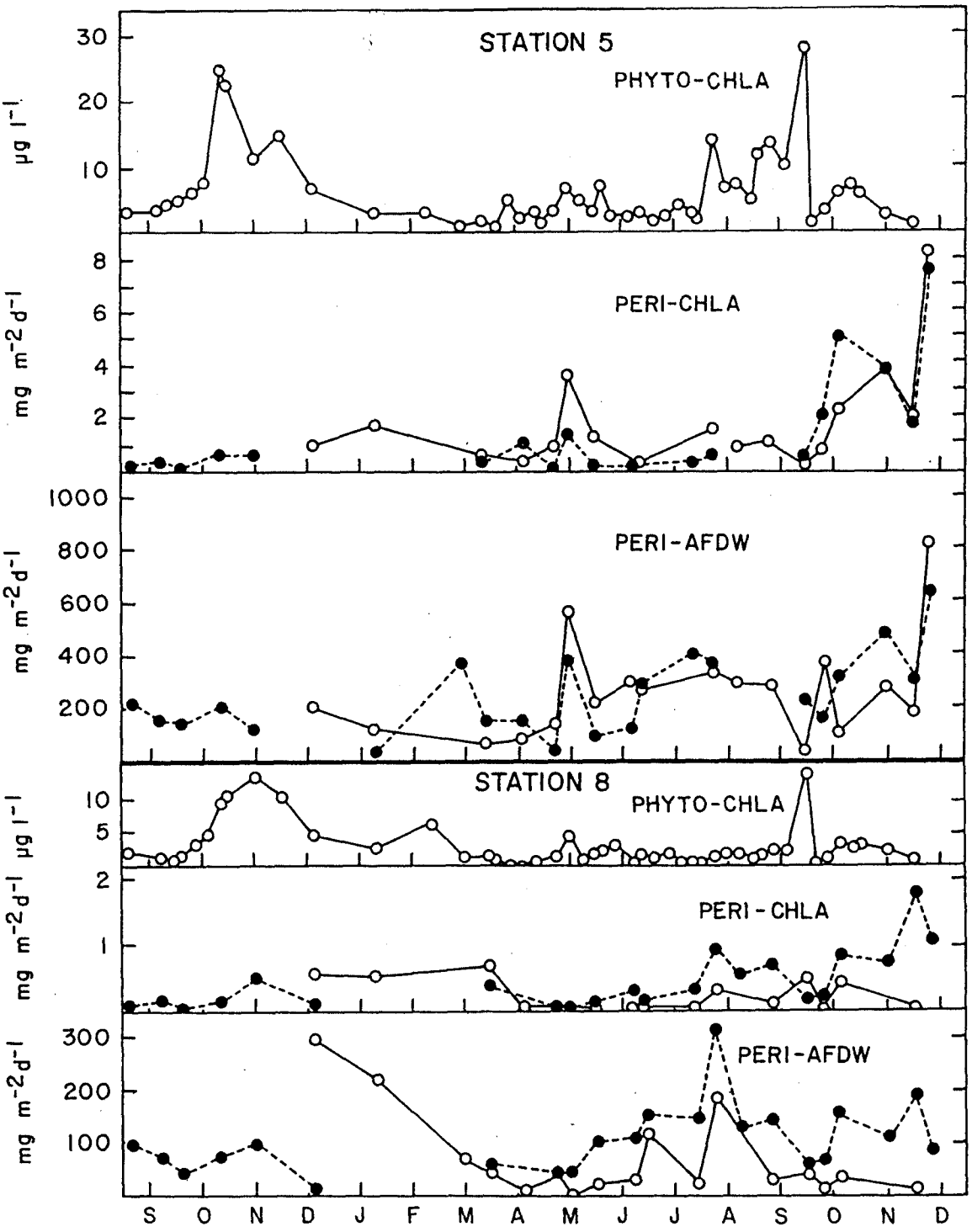
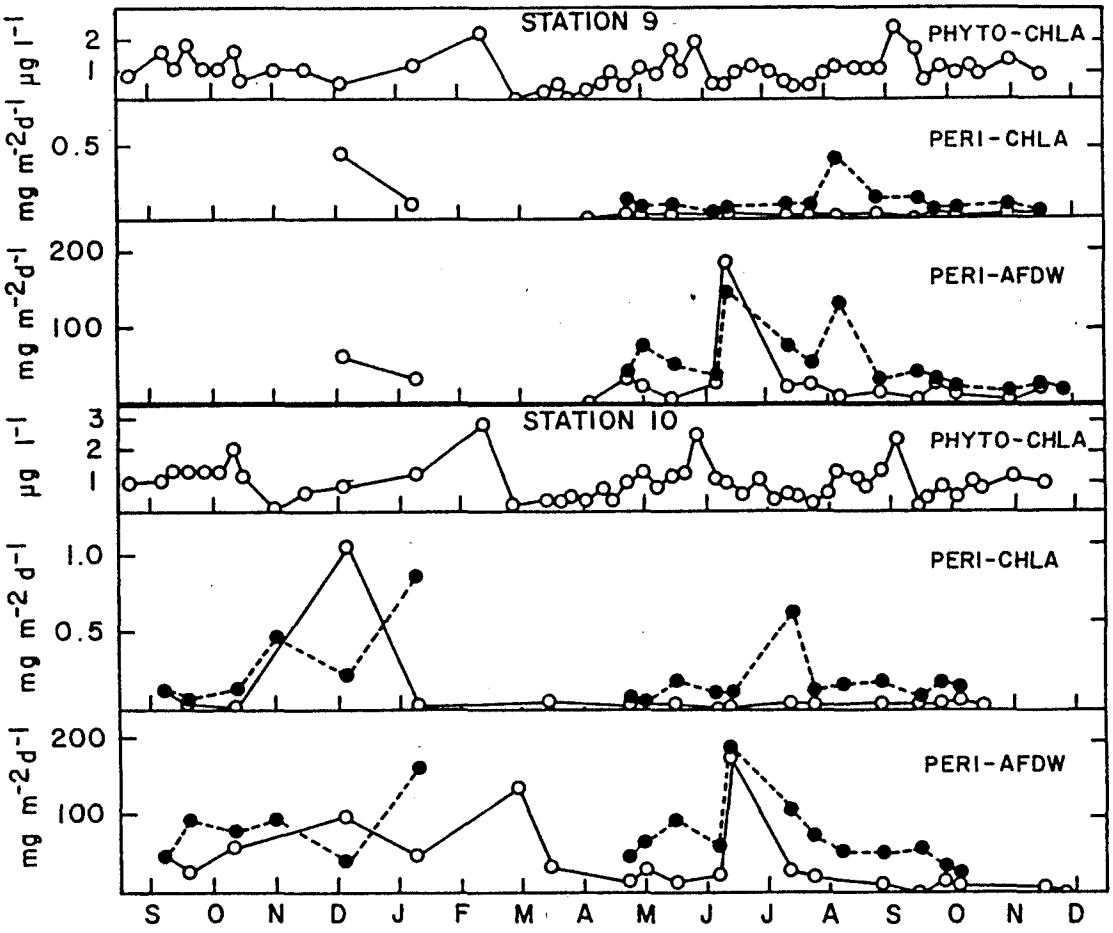

STATION 5
PHYTO-CHLA
μg l-1
30
20
10
PERI-CHLA
mg m-2d-1
8
6
4
2
PERI-AFDW
mg m-2d-1
1000
800
600
400
200
STATION 8
PHYTO-CHLA
μg l-1
10
5
PERI-CHLA
mg m-2d-1
2
1
PERI-AFDW
mg m-2d-1
300
200
100
S O N D J F M A M J J A S O N D

Figure 11. Phytoplankton chlorophyll-a concentrations (µg/l) and periphyton chlorophyll-a ($mg \cdot m^{-2} \cdot d^{-1}$) and ash-free dry weight ($mg \cdot m^{-2} \cdot d^{-1}$) accumulation rates at stations 9 and 10. Open circles are the limnetic stations and dark circles are the littoral stations.


STATION 9
PHYTO-CHLA
PERI-CHLA
PERI-AFDW
STATION 10
PHYTO-CHLA
PERI-CHLA
PERI-AFDW
μg l-1
mg m-2d-1
S O N D J F M A M J J A S O N D

185 $mg \cdot m^{-2} \cdot d^{-1}$ occurred in August. Productivity peaked earlier in the summer at stations 9 and 10 with 186 $mg \cdot m^{-2} \cdot d^{-1}$ and 178 $mg \cdot m^{-2} \cdot d^{-1}$ in June, respectively (Fig. 11). There was a secondary growth peak of 139 $mg \cdot m^{-2} \cdot d^{-1}$ at station 10 in March. Data are not available for station 9 during this time period.

Littoral stations exhibited somewhat different seasonal productivity patterns than limnetic stations (Fig. 12). Station 5 had a well developed blue-green mat community which was responsible for greater productivity than occurred at station 2 during summer. Spring data are not available for station 2 because of vandalism of samplers. However, fall biomass accumulation was greater than summer in the littoral habitat. This was due to a large bryozoan population, not periphyton, as reflected by the chlorophyll-a data. The winter peak observed at limnetic station 8 was not present in the data for the littoral habitat. Littoral station 9 had high growth in August (128 $mg \cdot m^{-2} \cdot d^{-1}$), a month after productivity had declined in the limnetic habitat (Fig. 11).

Littoral stations would be expected to have a greater biomass accumulation rate than limnetic stations because they are in close proximity to natural substrates and the seed population. This was generally observed at stations 8, 9, and 10 (Figs. 10 and 11). However, at station 2 the rate was lower in the littoral habitat (Fig. 9). This may have been due to a reduced period of light caused by the steep walled cliff rising above the station, but measurements were not made to evaluate this effect. The higher accumulation rate at station 5 alternated between the limnetic and littoral habitats. No consistant

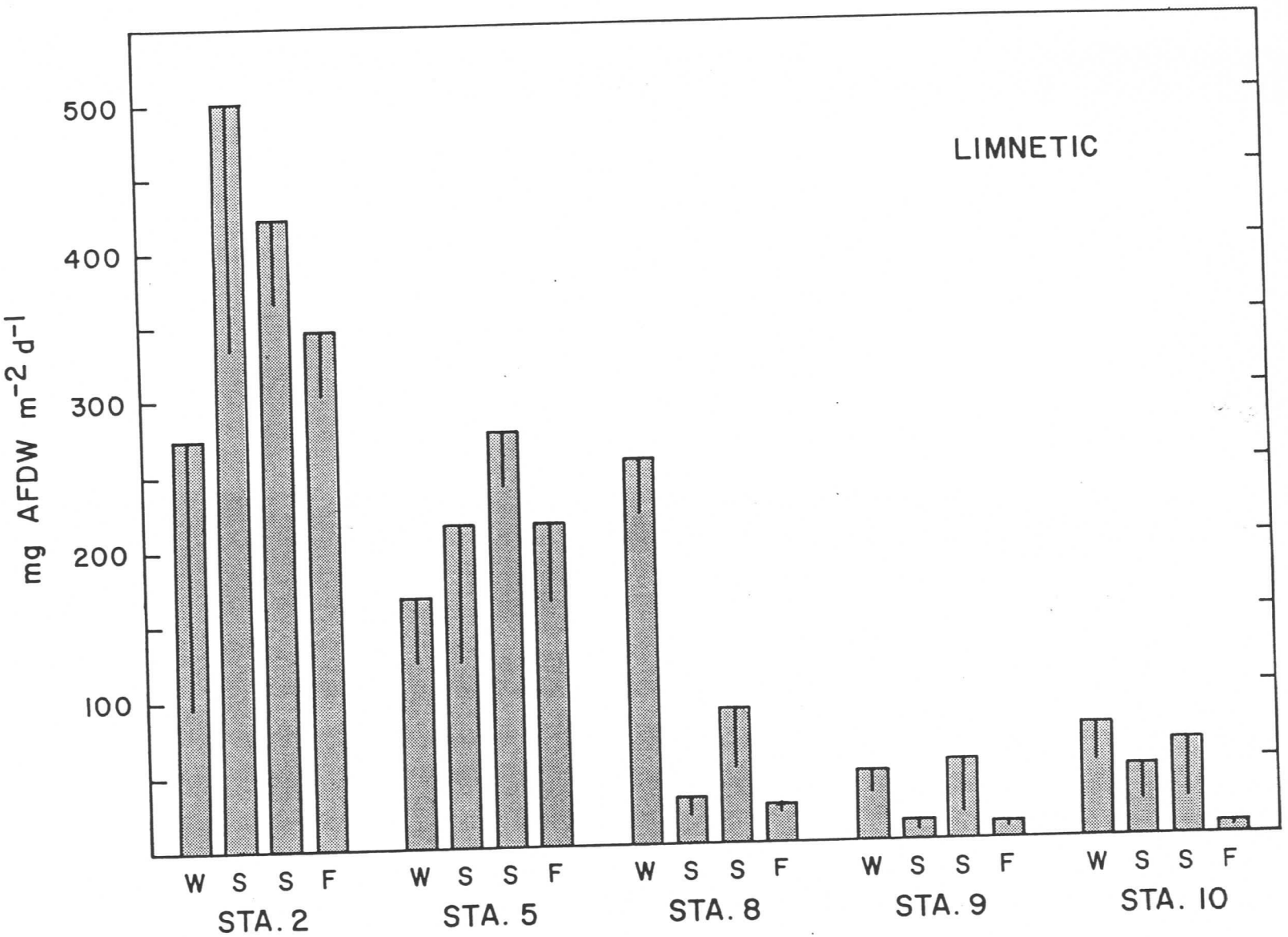
differences in nutrient concentrations between the two habitats were observed during several intensive surveys conducted during this study (Brown and Caldwell 1982).

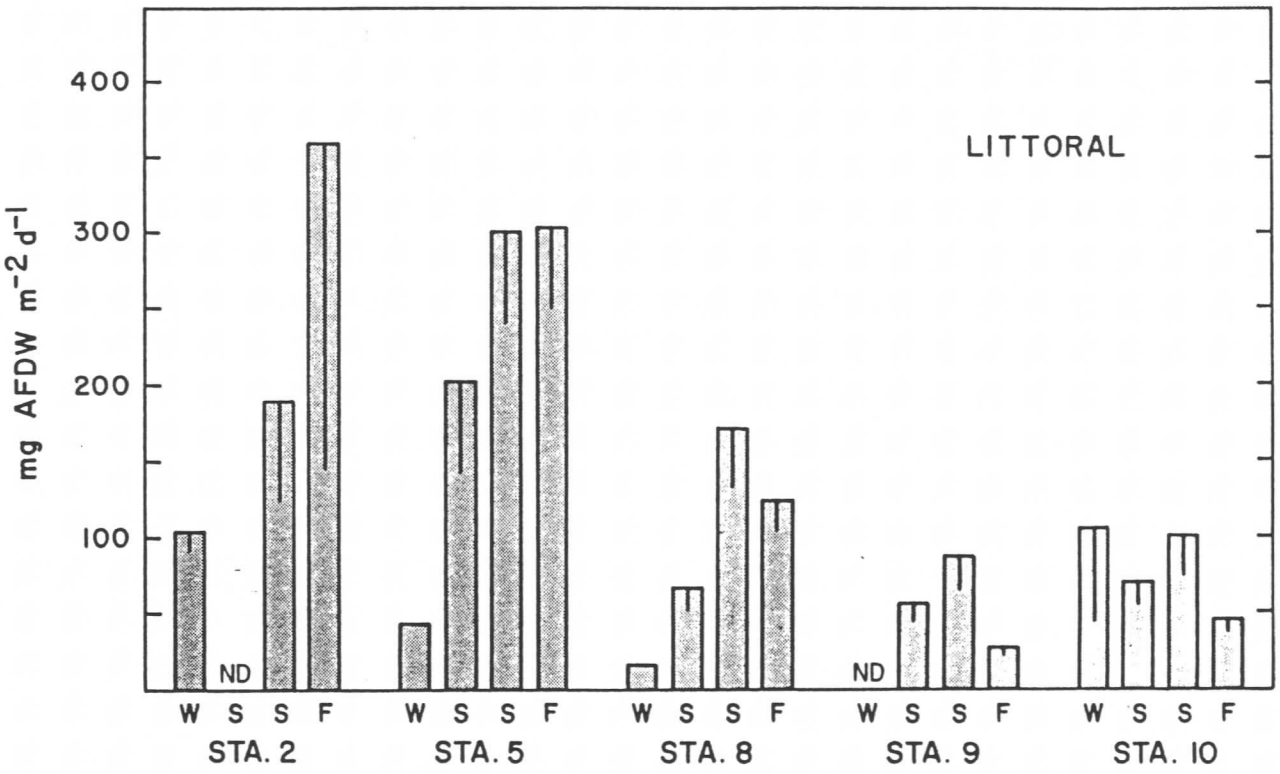
Periphyton productivity in Lake Mead, as estimated by biomass accumulation rate, showed a decreasing trend with increasing distance from Las Vegas Wash. A summary of average seasonal AFDW accumulations for limnetic and littoral stations is presented in Fig. 12. Data for fall 1979 and December 1980 are not included because missing data points prevented comparisons between stations.

Incubation Period

When biomass accumulation rates are compared between two week and four week substrate incubations, the longer incubation period generally resulted in greater accumulation rates (Appendix A). Accrual rate on artificial substrates generally follows a sigmoid curve with the lower part representing initial colonization and the upper part representing growth of an established community (Tilley and Haushild 1975). Assuming an established community has not been attained, the slow colonization phase becomes less evident when accrual rates are calculated from a longer incubation period. As a result, the two week incubation is probably a low estimate of productivity of the natural periphyton community. Two week and four week incubations were most comparable during the higher productivity intervals of spring and summer. These findings are in contrast to Castenholz (1960) who found two week and four week incubations comparable during low production periods, while slightly higher accrual rates occurred on the four week substrates

Figure 12. Average seasonal periphyton biomass accumulation rates ($mg \cdot m^{-2} \cdot d^{-1}$) from December 1979 through November 1980. Error bars are one standard error. ND is no data. W, S, S, and F under the bars correspond to winter, spring, summer, and fall, respectively.


LIMNETIC
mg AFDW m^{-2} d^{-1}
500
400
300
200
100
W S S F
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10


LITTORAL
mg AFDW $m^{-2} d^{-1}$
400
300
200
100
ND
ND
W S S F
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10

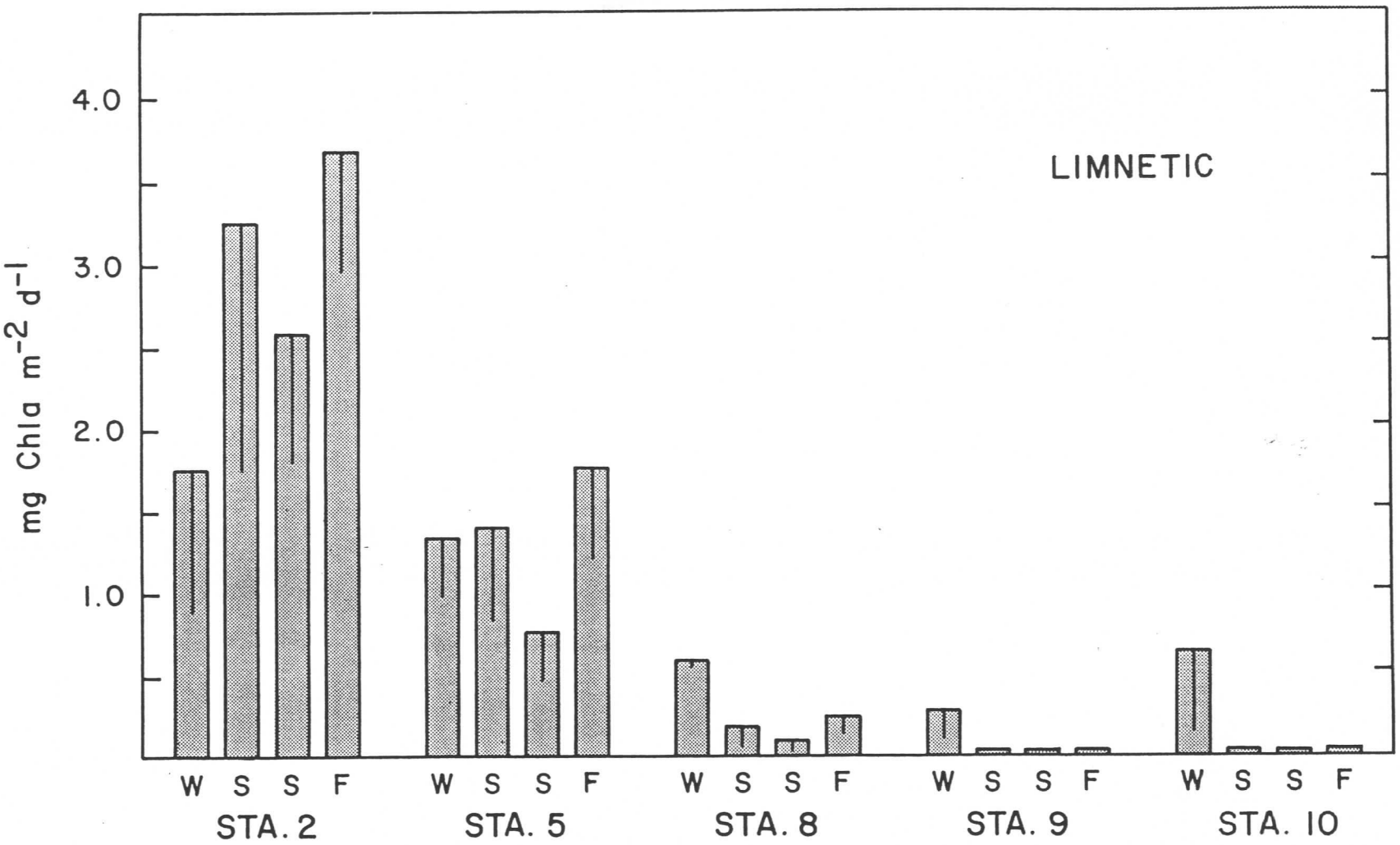
during higher spring production. Evidence of sloughing of periphyton was frequently observed on substrates incubated four weeks in my study. Sloughing results in underestimation of production.

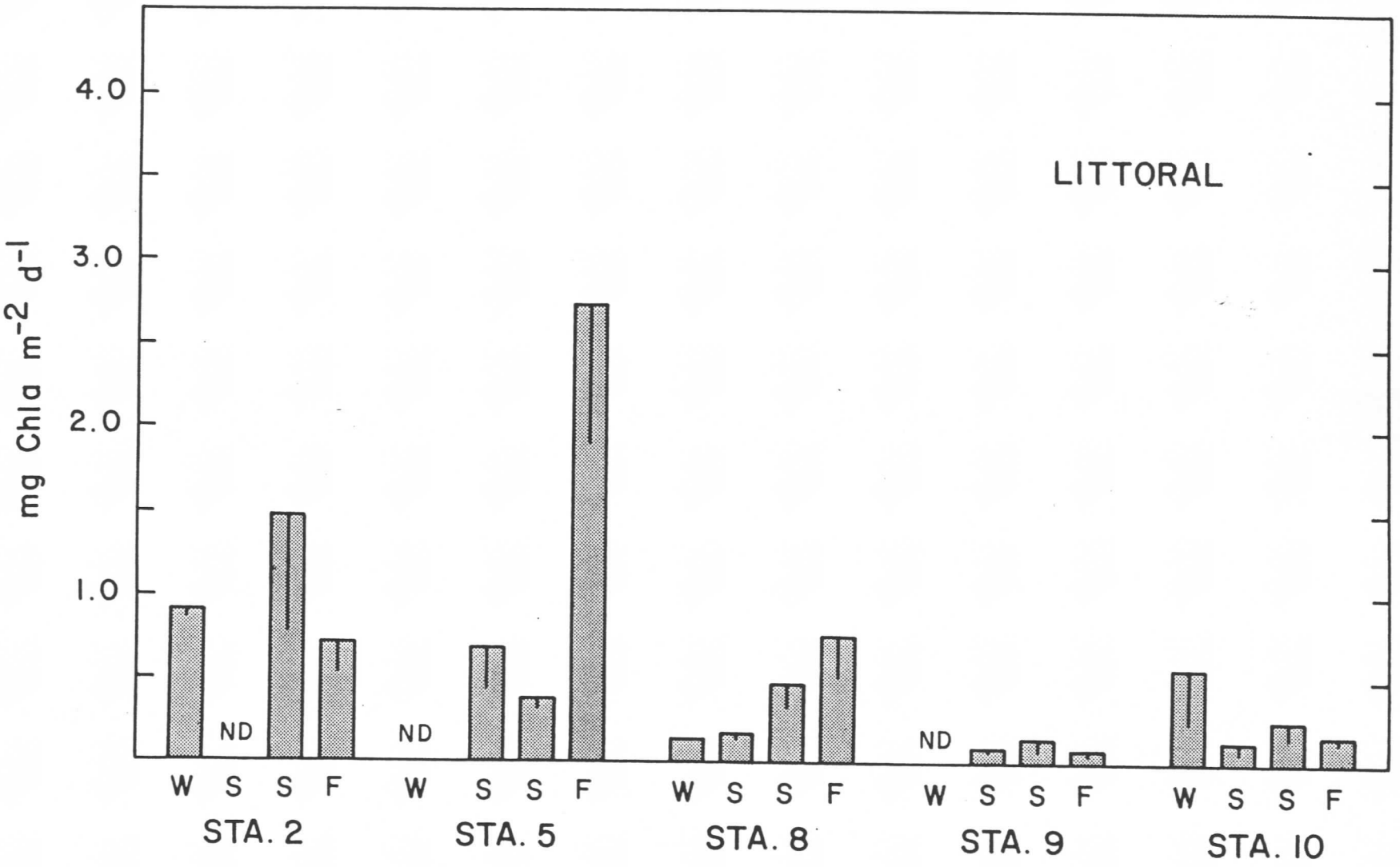
Periphyton Chlorophyll-a Production

Periphyton chlorophyll-a production also decreased with increasing distance from Las Vegas Wash (Fig. 13). Station 2 had the greatest chlorophyll-a production rates with a maximum value of 9.20 $mg \cdot m^{-2} \cdot d^{-1}$ in May (Fig. 9). A secondary peak was observed in fall 1980, reaching 5.68 $mg \cdot m^{-2} \cdot d^{-1}$ in November. The May maximum corresponded to a biomass accrual maximum, but there did not appear to be a similar relationship in fall. Lack of a good relationship between biomass and chlorophyll-a is due to the numerous variables affecting pigment concentration such as light, nutrition, and species composition (McConnell and Sigler 1959, Wetzel 1963, McIntire and Phinney 1965).

Station 5 had chlorophyll-a peaks in May and December 1980 (Fig. 10). These maximum concentrations were 3.55 $mg \cdot m^{-2} \cdot d^{-1}$ and 8.23 $mg \cdot m^{-2} \cdot d^{-1}$, respectively. The annual pattern of chlorophyll-a production corresponded well with that of biomass accumulation rate at this station. Stations 8, 9, and 10 had much lower rates of chlorophyll-a production. The maximum value recorded at station 8 was 1.81 $mg \cdot m^{-2} \cdot d^{-1}$ in the littoral habitat during November 1980 (Fig. 10). The chlorophyll-a peak at station 9 was 0.43 $mg \cdot m^{-2} \cdot d^{-1}$ at the limnetic station in December 1980, but values were at the lower level of detection (0.02 $mg \cdot m^{-2} \cdot d^{-1}$) during most of the year (Fig. 11). The littoral station had higher concentrations, averaging 0.01 $\pm$ 0.02

Figure 13. Average seasonal periphyton chlorophyll-a accumulation rates ($mg \cdot m^{-2} \cdot d^{-1}$) from December 1979 through November 1980. Error bars are one standard error. ND is no data. W, S, S, and F under the bars correspond to winter, spring, summer, and fall, respectively.


LIMNETIC
mg Chla m^{-2} d^{-1}
4.0
3.0
2.0
1.0
W S S F
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10


LITTORAL
mg Chla m^{-2} d^{-1}
4.0
3.0
2.0
1.0
ND
ND
ND
W S S F
STA. 2
STA. 5
STA. 8
STA. 9
STA. 10

$mg \cdot m^{-2} \cdot d^{-1}$ for the study period. Station 10 also had very low levels of chlorophyll-a at the limnetic station with the exception of 1.09 $mg \cdot m^{-2} \cdot d^{-1}$ measured in December 1980 (Fig. 11). The remainder of the year averaged 0.04 $\pm$ 0.01 $mg \cdot m^{-2} \cdot d^{-1}$. The littoral habitat generally had higher chlorophyll-a concentrations averaging 0.23 $\pm$ 0.05 $mg \cdot m^{-2} \cdot d^{-1}$ with peak values of 0.88 $mg \cdot m^{-2} \cdot d^{-1}$ and 0.64 $mg \cdot m^{-2} \cdot d^{-1}$ occurring in January and July, respectively.

Alkaline Phosphatase

Alkaline phosphatase is a membrane bound enzyme system, produced in many algae. It hydrolyzes phosphomonoesters such as adenosine monophosphate and glucose-6-phosphate extracellularly and assimilates only the phosphate radical, leaving the organic portion in solution (Kuenzler and Perras 1965, Kuenzler 1965). Alkaline phosphatase activity (APA) in phytoplankton has been shown to increase rapidly upon phosphorus depletion (Kuenzler and Perras 1965, Healey 1978, Perry 1972, Healey and Hendzel 1975), and enzyme synthesis is repressed in surplus phosphorus conditions (Kuenzler and Perras 1965, Jansson 1976).

An inverse relationship between PO_4-P and planktonic APA has been observed in Lake Mead (Kellar and Paulson 1981). There was no measurable activity in Las Vegas Bay where high levels of PO_4-P enter Lake Mead from Las Vegas Wash. However, PO_4-P concentrations decreased with increased distance from the Wash, and APA increased significantly along this gradient.

The periphyton community was analyzed for this enzyme to determine if it responded similarly to changes in PO_4-P availability. Alkaline

phosphatase activity was normalized for differences in periphyton growth by dividing by AFDW. Seasonal distributions in APA were erratic. Station 10 had the lowest PO_4-P concentration, and the greatest APA/AFDW ($\bar{x}$ = 19.92 x 10^{-4} nmoles PO_4 • min^{-1}•mg $AFDW^{-1}$) (Table 5). Conversely, station 2 had the highest PO_4-P concentration, and the lowest APA/AFDW ($\bar{x}$ = 1.81 x 10^{-4} nmoles PO_4 • min^{-1}•mg $AFDW^{-1}$). Station 5 had the second highest APA/AFDW ($\bar{x}$ = 10.60 x 10^{-4} nmoles PO_4 • min^{-1}•mg $AFDW^{-1}$). This was a result of high APA/AFDW during April - June that coincided with Cymbella affinis dominance. This diatom produces copious amounts of stalk material that was observed to be heavily colonized by bacteria. The bacteria may have been contributing to the high APA.

Despite this general trend, no statistically significant relationship between PO_4-P and APA could be established. The absence of a significant relationship between PO_4-P and APA may be related to growth characteristics of the periphyton community. During high productivity periods, growth on artificial substrates was up to 1 cm thick. This may create a microenvironment with different nutrient regimes available to organisms inhabiting lower layers than to those in surface layers. Ortho-phosphorus may be available to surface inhabiting organisms, but limiting in lower layers, thus increasing APA. When the assay is performed APA may be measured from subsurface organisms, resulting in an erratic relationship between APA and PO_4-P.

Species Composition

A summary of spatial and seasonal distributions of selected dominant periphyton species observed during this study is presented in

Table 5. Alkaline phosphatase activity (APA/AFDW) x 10^{-4} in periphyton*.

Date	Station 2	5	8	9	10
10-03-79	1.1				10.4
10-23	1.2				24.1
11-21	13.3				
12-20	2.0	5.3	37.4	6.7	105.9
1-25-80	0.9	0.7	2.0	4.4	7.2
3-25	0.9	0.9	ND		ND
4-15	2.3	73.3	12.5		
5-02	0.9	4.3	1.9	2.7	5.2
5-15	0.3	5.0	ND	ND	1.5
5-29	3.0	20.1	1.7	7.4	2.6
6-16	2.0	27.7	1.0	1.8	0.8
6-30	0.6	4.9	0.8	ND	0.2
7-25	1.2		6.7	4.7	8.4
8-07	0.5	7.1	12.3	0.2	3.2
8-21	0.1	4.4		ND	
9-08	3.8	7.6	11.4	26.8	68.9
9-23	1.2	12.8	19.8	0.4	47.6
10-07	1.2	5.8	0.3	0.7	49.9
10-20	1.4	1.7	4.3	1.7	2.8
11-06	1.3	7.6		ND	
11-20	0.2	0.8			ND
12-09	0.5	0.6			
$\bar{x}$	1.8	10.6	7.5	3.8	19.9

* units are nmoles $PO_4 \cdot min^{-1} \cdot mg\ AFDW^{-1}$
ND equals nondetectable

Table 6. A complete list of all species that occurred as dominants during this study is presented in Appendix B. Dominance is defined as the top five species ranked by cell volume. Each species must also represent greater than 1 % of the biomass in the sample to be considered dominant. Species colonizing limnetic samplers after two week incubations were true periphytic species, not opportunistic planktonic species as Wetzel and Westlake (1969) suggest. Vertical positioning of the samplers was probably responsible for precluding plankton from settling and establishing on the artificial substrates. Limnetic and littoral habitats had similar patterns of dominant species at each station.

Several species were notable for their predominance. Cymbella affinis dominated the community at stations 5, 8, 9, and 10 from about midwinter until June or July when Mougeotia became dominant (station 9 data available beginning April). Mougeotia is reported to thrive in oligotrophic water (Isrealson 1949 as cited in Gwendling 1971). It remained dominant through the end of the study (December 1980) at stations 8, 9, and 10. Dominance at station 5 changed to Stigeoclonium and Cladophora between October and November. At station 5, the green filaments were found in a mat community with blue-green filaments, the latter often exceeded the greens in cell volume.

Species composition was distinctly different and changed more frequently at station 2. Synedra ulna was dominant in late September and early October 1979. Greens dominated from late October through winter. Stigeoclonium was found with diatoms and blue-greens through early summer. The community then became dominated by diatoms until December

Table 6a. Seasonal distributions of selected periphytic species at limnetic stations. Numbers correspond to stations.

TAXA	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
BACILLARIOPHYTA																
Achnanthes minutissima					8 9			8 10	5 8 9	5 8 9	8					
Anomoeoneis vitrea	10	10		10						9	9 10	9 10	8 9 10	9 10	9	
Cymbella affinis					5 8		2 5 8 10	2 5 8	2 5 8 9 10	5 8 9 10		9			2	
C. microcephala									5 8 9	5 8 9 10	9					
C. minuta	10	10														
C. pusilla									10	8 9 10	8 9 10	9	9 10	9 10	9	
C. tumida							2		2	2				2	2	2
Fragilaria capucina				2	2		2	2	2							
Gomphonema olivaceum							5 8	5 8								
Mastogloia smithii												2	2			
											9		9	9		
Melosira varians				2	2				2						2 5	2
Navicula cincta										2	2	2		2	2	
Nitzschia denticula									9 10	8 9 10	10	10	10		10	

continued

Table 6a continued.

TAXA	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
N. palea				2			8		2	2			2	2	2	
Synedra ulna	2	2			5 8 9		5 10	5	2 5	2	2 8	2 5 9 10	5 9 10	2 5 8 10	5 8 10	2
CHLOROPHYTA																
Cladophora sp.															5	5
Mougeotia sp.	10	2 10		10	9				9 10	5 10	5 8 9 10	5 8 9 10	5 8 9 10	2 5 8 9 10	5 8 9 10	
Oedogonium sp.		2														
Oocystis gigas		2	2	2						8			10 2 5			
Plectonema lauterborinii		10					10						2 5 8 9	5 9 10	9	
Spirogyra sp.		2 10		2	2				8				5		2	
Stigeoclonium sp.				2			2	2	2	2					5	
CYANOPHYTA																
Lyngbya aestuarii								2					5			
Phormidium favosum					5		8		2						2	2
Spirulina major									5							

Table 6b. Seasonal distributions of selected periphytic species at littoral stations. Numbers correspond to stations.

TAXA	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
BACILLARIOPHYTA																
Achnanthes minutissima									5	5						
							8		8	8						
Anomoeonis vitrea										2					2	
							8									
	10		10	10					10	9 10	9 10	9 10	10	9 10	9	9
Cymbella affinis					5		5	5	5	5				2		
		8	8	8			8		8	8					8	8
									9	9						
				10	10				10	10						
C. microcephala									5	5						
										9						
										10						
C. minuta																
	10	10	10													
C. pusilla										8			8			
									9	9		9	9	9	9	
									10	10	10	10	10	10		
C. tumida					2										2	2
															8	
Fragilaria capucina				2												
									8							
Gomphonema intricatum											2	2				
										8		8				
									9		9		9	9	9	
G. olivaceum							8									
Mastogloia smithii													5			
	8	8									8	8	8	8		
	10	10								9			9			
Melosira varians					2										2	2
Navicula cincta										2						
Nitzschia denticula											2					
									8							
									9	9	9					
		10							10	10	10	10	10	10		

continued

Table 6b continued.

TAXA	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
N. palea	2				5		5	5	5	2				2		
														10		
Synedra ulna	2	2	2						5	5		2		2		
									8	8				5		
												9	9	8		
		10		10									10			
CHLOROPHYTA																
Cladophora sp.		2													5	
Mougeotia sp.		2										2			2	
	5	5											5	5		
	8	8	8	8						8	8		8	8	8	
											9	9	9	9	9	9
	10	10	10	10	10						10	10	10	10		
Oedogonium sp.	2	2										2				
		5	5						5							
	8	8									8		8			
											9	9	9	9	9	9
													10			
Oocystis gigas		2	2	2											2	
	5	5	5		5										5	
		8	8	8											8	
					10											
Plectonema lauterborinii													2	2	2	
													5			
													8	8	8	
		10												10		
Spirogyra sp.		2	2		2											2
		5	5											5	5	
CYANOPHYTA																
Lyngbya aestuarii														2		
	5	5	5				5	5			5	5	5	5	5	
														8		
														9		
Phormidium favosum															2	
					5		5	5	5						5	
															8	8
					10											
Spirulina major									5	5						
		10														

when Stigeoclonium reappeared. Mougeotia was conspicuously sparse.

A tally of taxon, whose distributions as a dominant were limited to one station, indicates station 2 was the most unique with 19 taxa found only at that location. Stations 5, 8, 9, and 10 had 4, 4, 1, and 3 unique taxa, respectively. Stations 2 and 5 appeared different from other stations in several respects. They were the only stations where blue-green algae were dominant taxa in every season. Blue-green filaments were an especially important component at littoral station 5 which was often characterized by a dense blue-green mat community. Blue-green algae were dominant at all stations, except limnetic station 9, at least once during the study period. The diatom Gomphonema parvulum was found only at stations 2 and 5 (Appendix B). Lowe and McCullough (1974) found this species to be favored by sewage effluent. Melosira varians is an indicator of eutrophic conditions (Reimer 1965) and was also limited in distribution to stations 2 and 5. Conversely, Stockner and Armstrong (1971) consider Achnanthes minutissima to be characteristic of the littoral zone of oligotrophic, temperate lakes; this diatom was found as a dominant species everywhere in Lake Mead, except station 2.

Contrary to APHA (1981), I did observe adult thalli of Stigeoclonium after only a two week incubation. Adult Cladophora was found growing on the rough cut edges of the fiberglass substrates, but not on the smooth face that was sampled. This indicated the substrate was not suitable for attachment, rather than an insufficient incubation period or the reproductive nature of the genus as Castenholz (1960) suggests. These taxa were found only at stations 2 and 5 on the

artificial substrates, but were observed lake-wide on natural substrates.

DISCUSSION

Periphyton productivity in Lake Mead is similar to that reported for other lakes and reservoirs (Table 7). Lake Kinneret has nitrogen and phosphorus concentrations comparable to those at Lake Mead stations 5 through 10.

Periphyton production in Lake Mead followed the same spatial trend as PO_4-P, NH_3-N, and phytoplankton standing crop. The highest production was measured in Inner Las Vegas Bay (station 2), and the lowest in Virgin Basin (station 9). The greater phytoplankton standing crop (as chlorophyll-a) at station 2 reduced secchi depth during the summer to above the 2 m sampler depth (Fig. 4). All other stations had secchi depths below sampler depth (3 m), with the exception of station 5 on two dates. Phytoplankton and periphyton increased at station 2 in spring, but periphyton declined in early summer while phytoplankton continued to increase. When phytoplankton declined in fall and secchi depth increased to 2 m, periphyton chlorophyll-a increased (phytoplankton chlorophyll-a and periphyton chlorophyll-a: $r=-0.93$, $p=0.004$) (Table 8), but AFDW did not. The increased ratio of chlorophyll-a to AFDW could not be attributed to changes in species composition. The gradual nature of the increase could reflect a response to decreased light intensity (McIntire and Phinney 1965). This was not observed at other stations. The distinct alternation between periphyton and phytoplankton growth peaks at station

Table 7. Periphyton productivity in Lake Mead and other lentic systems.

LOCATION	SUBSTRATE	PRODUCTIVITY ($mg \cdot m^{-2} \cdot d^{-1}$)	REFERENCE
Lake Mead, NV-AZ	fiberglass	$\bar{x}$ = 171	present study
Las Vegas Bay, Lake Mead (sta. 2)	fiberglass	$\bar{x}$ = 401	present study
Bonelli Bay, Lake Mead (sta. 10)	fiberglass	$\bar{x}$ = 44	present study
Soap Lake, WA	glass	$\bar{x}$ = 167	Castenholz 1960
Sedlice Reservoir, Czech.	glass	$\bar{x}$ = 213	Sladecek & Sladeckova 1964
Lake Kinneret, Israel	glass	$\bar{x}$ = 220	Dor 1970
Lake Tahoe, CA-NV	glass	0.2-4.4	Goldman 1974
Lake Tahoe, CA-NV	styrofoam	17.1 max.	Flint 1977

Table 8. Pearson correlation coefficients for periphyton and environmental parameters.

Station	Season	Independent Variable	Dependent Variable AFDW r(n)p	Dependent Variable CHLA r(n)p
2	fall 1979	PO -P	.82(5).04	#
		secchi *	-.89(5).02	-.88(5).03
	spring 1980	NH -N	-.96(4).02	
		PCHL **		.98(5).001
	fall 1980	NO +NO -N	-.84(6).02	
		temperature		-.93(6).004
		secchi		.74(6).04
		PCHL		-.93(6).004
5	spring 1980	secchi	-.87(5).03	-.83(5).04
		PCHL	.98(5).001	.98(5).002
	summer 1980	PO -P		-.95(4).02
		temperature		.99(4).01
		secchi		-.98(4).01
		PCHL		.99(4).005
	fall 1980	NH -N		.96(6).001
		temperature		-.72(6).05
8	spring 1980	PO -P	.76(6).04	
	summer 1980	NH -N	-.99(3).05	
	fall 1980	PCHL	.82(5).04	.80(5).05
9	fall 1980	NH -N	-.73(6).05	
10	spring 1980	PO -P	.98(5).002	
		NO +NO -N		.91(4).04
		temperature	-.80(5).05	
		secchi		.98(4).01
		PCHL		-.97(4).01

missing data equals $p>0.05$
* secchi is log transformed
** PCHL equals phytoplankton chlorophyll

2 suggests that there is competition for light. Jorgensen (1957) observed this in two eutrophic Danish lakes, as did Wetzel (1964) in shallow, saline Borax Lake.

Periphyton growth at station 2 correlated with PO_4-P ($r=0.82$, $p=0.04$) (Table 8) only in fall 1979 when PO_4-P concentrations were the lowest. There was an inverse relationship between AFDW and NH_3-N in spring ($r=-0.96$, $p=0.02$) (Table 8). This can be attributed to stratification events in conjunction with phytoplankton dynamics. The spring decrease of NH_3-N occurred as phytoplankton increased and stratification began. Because the periphyton did not respond to the pulses of nitrogen that occurred in August, it appears that light is the primary factor and nitrogen the secondary factor limiting periphyton in Inner Las Vegas Bay.

Nutrient concentrations are reduced by phytoplankton uptake and dilution (Baker and Paulson 1980) of the Las Vegas Wash inflow as it moves toward Hoover Dam. Periphyton and phytoplankton production were reduced accordingly at limnetic station 5. Periphyton and phytoplankton gradually increased during spring and summer at station 5. The growth peaks of the two communities, however, were offset. Lowest periphyton production coincided with highest phytoplankton standing crop (23 September 1980) and very low concentrations of PO_4-P, NH_3-N, and NO_2+NO_3-N (2, 2, and 14 µg/l respectively). Nitrogen was depleted during most of the stratified period at station 5. Peak periphyton production occurred in December 1980, with a smaller peak in May. Nitrogen data were not available for December 1980, but periphyton chlorophyll-a correlated strongly with NH_3-N in fall 1980 ($r=0.96$, $p=0.001$) (Table 8).

In addition, the growth peak in May occurred after a pulse in NH_3-N. Since secchi depth was below sampler depth, light was not a limiting factor. Nitrogen was, therefore, the most probable factor limiting periphyton growth at this location.

Periphyton and phytoplankton growth at station 8 was reduced even further by decreased nutrient supply, although phytoplankton standing crop was still two times and periphyton standing crop three times higher than Virgin Basin (station 9). The peak AFDW accumulation rate during winter at limnetic station 8 was not reflected in chlorophyll-a measurements. There was a build-up of Cymbella affinis stalk material and associated bacteria on the substrates, with live cells limited to the surface layer. Growth rate estimates by AFDW may have been artificially high during this period. The influence of the Colorado River could be seen in higher NO_2+NO_3-N concentrations at station 8 than at station 5. Phosphorus and nitrogen reached undetectable levels at station 8 periodically in summer and fall. Seasonal inorganic N:P ratios ranged from 67 in spring to 16 during summer stratification. On isolated occasions, the ratio was less than 5. It appears phosphorus and nitrogen were alternately limiting, although there were no statistically significant relationships.

Upper lake stations 9 and 10 were characterized by the nutrient regime of the Colorado River and were independent of Las Vegas Wash influence. Algae productivity was low. Ortho-phosphorus was below detectable limits from August through October and apparently too low to allow phytoplankton to deplete NO_2+NO_3-N (Paulson and Baker 1979). Peak AFDW was measured at limnetic stations in summer before PO_4-P depletion.

With seasonal N:P ratios greater than 100, phosphorus must certainly be a limiting growth factor in the upper basin.

Phosphorus reduction by advanced wastewater treatment is being implemented to reduce phytoplankton productivity in Las Vegas Bay. If light is limiting periphyton in Las Vegas Bay as evidence suggests, and there is shading of periphyton by phytoplankton, reduction in phytoplankton could result in an increase in periphyton. Lakes with low nutrients and phytoplankton growth can still support high periphyton growth (Moss 1968). Smrchek et al. (1976) found tertiary treated effluents significantly stimulated periphyton growth in laboratory streams. Although water clarity would increase, some beneficial uses could be adversely affected by decreases in phytoplankton. This shift would have repercussions on fisheries by reducing food supply, on swimming by increasing attached algae on beaches, and on boating by requiring increased boat maintenance. Periphyton studies on natural substrates and boat hulls would be required to define the extent of these potential impacts.

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Appendix A.

COLLECTION DATE	*	LIMNETIC AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LIMNETIC CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)	LIMNETIC APA nmoles $PO_4 \cdot m^{-2} \cdot min^{-1}$ (n=3)	LITTORAL AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LITTORAL CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)
STATION 2						
9-07-79	17	518(95)**	1.16(0)		264(6)	0.60(.04)
9-19	12	275(8)	1.15(.04)		242(42)	1.13(.30)
	29	379 #	1.06		303	1.70
10-03	14	357(58)	1.12(.06)	0.5500(.0137)	228	0.66
	43	1014	0.21		298	0.42
10-23	21	496(212)	1.42(.23)	1.1988(.0016)	296(10)	0.90(.37)
11-21	28	96(4)	0.34(.04)		160(33)	0.82(.20)
	49	376	1.23		376	0.32
12-20	30	450(30)	2.65(.63)	2.7242(.1076	114(6)	0.87(.19)
	79	33	0.03		81	0.59
1-25-80	36	261(6)	0.94(.09)	0.3109(.0208)	92(12)	0.94(.19)
	66				109	0.88
3-07	30	44(4)				
3-25	15	326(34)	2.10(.91)	0.4452(.1134)		
4-15	21	238(87)	3.07(.11)	1.1628(.0504)		
	36	244	1.02			
5-02	17	441(54)	0.98(.25)	0.6480(.0519)		
	53	290	ND##			
5-15	13	869(179)	0.88(.88)	0.3734(.0388)		
5-29	14	1072(187)	9.20(1.38)	4.4942(.4628)		
	27	859	3.22			
6-16	14	514(14)	5.52(1.29)	1.4497(.1006)	343(0)	4.03(.70)
6-30	14	300(72)	1.78(.28)	0.2761(.0414)	93(7)	0.96(.10)
7-25	25	568	2.68	1.7095(.0389	116(28)	1.47(.41)
	39	374	1.22		51	0.49
8-07	13	308(78)	1.50(.69)	0.1856(.0141)	62(0)	0.40(.31)
	52	1023	0.08		431	0.44
8-21	14	414(43)	1.44(.20)	0.0530(.0122)	336(108)	0.51(.01)
9-08	18	206(6)	1.54(.69)	1.4192(.0092)	1361(17)	0.06(.02)
	32	2038	0.28		962	0.03
9-23	15	446	1.76(.88)	0.8093(.0197)	346(67)	0.70(.17)
10-07	13	392(179)	3.26(1.15)	0.6184(0)	254(23)	1.00(.08)
	28	1057	1.74		1385	0.40
10-20	13	362(54)	4.47(.20)	0.6470(.0111)	62(0)	0.33(.15)
	41	1102	2.42		536	0.07
11-06	17	424(24)	5.34(.18)	0.9140(.0277)	82(12)	1.12(.16)
11-20	14	242(72)	5.68(.86)	0.0694(.0051)	50(7)	1.01(.13)
	31	110	2.13			
12-09	19	216(27)	3.45(.31)	0.1993(.0025)	53(0)	1.44(.08)

Appendix A continued.

COLLECTION DATE	*	LIMNETIC AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LIMNETIC CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)	LIMNETIC APA nmoles $PO_4 \cdot m^{-2} \cdot min^{-1}$ (n=3)	LITTORAL AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LITTORAL CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)
STATION 5						
9-07-79	17				230(18)	0.25(.03)
9-14	12				158(25)	0.47(.01)
	29				310	0.43
10-03	14				150(7)	0.20(.08)
	43				646	0.55
10-23	21				210(58)	0.68(.12)
11-21	28				121	0.68(.31)
	49				347	0.13
12-20	57	210(43)	0.99(.17)	6.3812(.1410)		
1-25-80	37	124(16)	1.66(.22)	0.3157(.0529)	42(6)	
	66	289				
3-25	15	66(14)	0.68(.07)	0.0853(.0232)	154(6)	0.46(.01)
4-15	21	86(19)	0.46(.06)	13.2386(3.1662)	152(19)	1.05(.22)
	36	850	ND		156	0.46
5-02	17	147(6)	0.99(.20)	1.0780(.0590)	47(23)	0.14(.04)
	53	196	0.34		102	0.09
5-15	13	554(218)	3.55(.57)	3.5995(.0976)	376(54)	1.42(0)
5-29	14	222(65)	1.28(.60)	6.2383(.4619)	100(14)	0.30(0)
	27				67	0.22
6-16	18	300(123)	0.36(.03)		134(23)	0.24(.03)
	45	876	0.17		89	0.12
6-30	14	171(0)	0.23(.01)	1.1757(.0673)	292(22)	0.30(.01)
7-25	25				408(48)	0.41
	39				200	0.34
8-07	13	338(16)	1.54(.49)	3.1212(.1577)	369	0.58
	52	615	1.59			
8-21	14	300(101)	0.88(.08)	1.8407(.0471)		
9-08	18	289(79)	1.11(.08)	3.9758(.2246)		
	32	394	1.24			
9-23	15	47(20)	0.20(.12)	0.9009(.0720)	240(81)	0.64(.22)
10-07	13	376(85)	0.96(.06)	2.8572(0.0333)	162(39)	2.03(1.55)
	28	357	1.01		307	0.94
10-20	13	108(16)	2.32(.11)	0.2341(.0128)	331(70)	5.10(.70)
	41	995	0.96		756	3.72
11-06	17	282(95)	3.94(.87)	3.6535(.2451)	482(12)	3.92(.08)
11-20	14	186(101)	1.98(.20)	0.2170(.0040)	307(80)	1.83(.67)
	31	361	3.99			
12-09	19	821(21)	8.23(.43)	0.8684(0)	647(165)	7.56(1.44)

Appendix A continued.

COLLECTION DATE	*	LIMNETIC AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LIMNETIC CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)	LIMNETIC APA nmoles $PO_4 \cdot m^{-2} \cdot min^{-1}$ (n=3)	LITTORAL AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LITTORAL CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)
STATION 8						
9-07-79	17				100(6)	0.08(.02)
9-19	12				75(8)	0.19(.01)
	29				90	0.26
10-03	14				42(15)	0.04(0)
	43				158	0.16
10-23	20				80(20)	0.18(0)
11-21	29				100(38)	0.52(.04)
	49				188	0.24
12-20	57	295(42)	0.58(.16)	62.8052(19.046)	16(2)	0.12(.02)
	78				244	0.15
1-25-80	36	220(21)	0.56(.15)	2.6072(.0576)		
	66	331				
3-07	31	71(0)				
3-25	15	40(0)	0.70(.02)	ND	66(14)	0.39(.05)
4-15	21	10(0)	0.06(0)	0.2619(.0178)		
	36	33	0.09			
5-03	17	35(12)	0.06	0.1122(0)	47(0)	0.04(.01)
	53	23	0.05			
5-15	13	ND	0.03(.02)	0.0106(.0108)	46(0)	0.02(0)
5-29	14	21(7)	ND	0.0509(.0006)	107(50)	0.15(.05)
	27	30	0.04		148	0.20
6-16	18	28(6)	0.01(0)	0.0482(.0089)	116(6)	0.30(0)
	45	84	0.01		98	0.22
6-30	14	122(65)	0.02(.02)	0.1371(.0106)	150(65)	0.15(.01)
7-25	25	21(5)	0.02(0)	0.3525(.0038)	144(0)	0.29(.07)
	39	64	0.07		144	0.11
8-07	13	185	0.32	2.9571(.0585)	315(23)	0.93(.05)
	52				192	0.52
8-21	14				128(15)	0.58(0)
9-08	18	28(6)	0.13(.01)	0.5756(.0331)	139(28)	0.68(.11)
	32				269	0.48
9-23	15	40(0)	0.49(.12)	1.1862(.0158)	67(0)	0.19
10-07	13	15(0)	0.03(.01)	0.0061(.0031)	70(8)	0.18(.01)
	28	43	0.05		250	0.44
10-20	13	31	0.41	0.1726(.0086)	154(31)	0.84(.12)
	41	410	1.18		332	0.59
11-06	17				118(36)	0.74(.04)
11-20	14	14(0)	0.03(0)		186(43)	1.81(.16)
	31	6	0.02			
12-09	19				84(21)	1.09(.18)

Appendix A continued.

COLLECTION DATE	*	LIMNETIC AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LIMNETIC CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)	LIMNETIC APA nmoles $PO_4 \cdot m^{-2} \cdot min^{-1}$ (n=3)	LITTORAL AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LITTORAL CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)
STATION 9						
12-20-79	57	64(11)	0.43(.08)	4.8289(.6714)		
1-25-80	36	33(0)	0.10(0)	0.5337(.0366)		
4-15	21	ND	ND			
	36	11	0.04			
5-02	17	30(6)	0.02(.01)	0.1369(.0168)	41(6)	0.12(0)
	53	30	0.07			
5-15	13	23(8)	0.01(0)	ND	77(0)	0.06(.04)
5-29	14	6(.5)	0.01(.01)	0.0662(.0092)	50(7)	0.08(0)
	27	30	0.07		30	0.07
6-16	18	22(0)	ND	0.0721(.0056)	38(6)	0.03(0)
	45	67	0.10		27	0.04
6-30	14	186	0.02(0)	ND	143(58)	0.06(0)
7-25	25	20(4)	ND	0.2347(.0047)	76(4)	0.08(0)
	39	31	0.02		102	0.22
8-07	13	23(8)	0.01(.01)	0.0067(.0057)	54(8)	0.08(.02)
	52	35	0.03		100	0.32
8-21	14	7(7)	ND	ND	128(43)	0.38(.11)
9-08	18	11(0)	0.02(.02)	0.5352(.0202)	28(17)	0.12(.04)
	32	19	0.02		125	0.49
9-23	15	6(6)	ND	0.0035(.0035)	40(13)	0.12(.02)
10-07	13	23(8)	0.01(0)	0.0218(.0108)	31(0)	0.06(.02)
	28	36	0.13		64	0.20
10-20	13	8(0)	0.01(.01)	0.0169(.0042)	23(8)	0.06(.02)
	41	68	0.44			
11-14	17	2(.5)	0.02(0)	ND	18(6)	0.09(0)
	14	19	0.37		13	0.01
11-20	31	14(0)	0.01(0)		21(7)	0.02(.01)
12-09	19				16(6)	

Appendix A continued.

COLLECTION DATE	*	LIMNETIC AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LIMNETIC CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)	LIMNETIC APA nmoles $PO_4 \cdot m^{-2} \cdot min^{-1}$ (n=3)	LITTORAL AFDW $mg \cdot m^{-2} \cdot d^{-1}$ (n=2)	LITTORAL CHLA $mg \cdot m^{-2} \cdot d^{-1}$ (n=3)
STATION 10						
9-19-79	29	55(0)	0.12(.05)		48(0)	0.13(.03)
10-03	14	28	0.03(.01)	1.4498(.0196)	100(43)	0.06(.04)
	43		0.11		93	0.12
10-26	23	61(9)	0.02(.01)	3.3764(.0452)	83(13)	0.15
11-21	26				100(15)	0.48(.04)
	49				118	0.31
12-20	55	100(16)	1.09(.12)	46.6145(1.4387)	45(9)	0.24(.01)
	78	82	0.86		36	0.29
1-25-80	36	50(24)	0.13(.12)	1.3044(.1437)	166(23)	0.88(.25)
	66	176	1.10		352	
3-25	18	39(24)	0.06(.03)	ND		
5-02	17	18(8)	0.02(.01)	0.1562(.0308)	47(0)	0.08(.01)
5-15	13	31(0)	0.01(0)	0.0613(.0314)	69(23)	0.05(0)
5-29	14	14(0)	0.01(.01)	0.0519(.0076)	93(7)	0.20(.06)
	27	15	0.02		52	0.09
6-16	18	22(0)	ND	0.0342(.0024)	62(6)	0.11(.01)
	45	27	0.03		142	0.28
6-30	14	178(11)	0.01(.01)	0.1094(.0056)	192(79)	0.13(.01)
7-25	25	32(0)	0.02(0)	0.6708(.0360)	112(0)	0.64(.21)
	39	36	0.03		185	0.29
8-07	13	23(11)	0.01(0)	0.0968(.0301)	77(15)	0.14(0)
	52	27			281	0.46
8-21	14				57(14)	0.16(.06)
9-08	18	11(0)	0.03(0)	1.3783(.0439)	56(0)	0.19(.01)
	32		0.10		112	0.55
9-23	15	ND	0.03	0.2381(.0066)	60(7)	0.10(.11)
10-07	13	15(0)	0.03(.02)	0.9976	38(8)	0.19(.04)
	28	21	0.24		121	0.38
10-20	13	9(6)	0.05(.02)	0.0325(.0003)	31(0)	0.16(.04)
	41	73	0.45		161	0.32
11-20	14	8(2)	0.01(0)	ND		
12-09	19	ND				

* incubation (days)
** mean(S.E.)
\# if no S.E. is presented, n=1
ND equals nondetectable

Appendix B.

BACILLARIOPHYTA

Achnanthes minutissima Kutz.
Amphipleura pellucida Kutz.
Amphora acutiuscula Kutz.
coffeiformis (Ag.) Kutz.
purpusilla Grun.
Anomoeoneis vitrea (Grun.) Ross
Bacillaria paradoxa Gmelin
Cyclotella atomus Hust.
glomerata Bachm
meneghiniana Kutz.
Cymbella sp. Ag.
affinis Kutz.
cymbiformis v. *nonpunctata* Font.
microcephala Grun.
minuta Hilse ex Rabh.
prostrata v. *auerswaldii* (Rabh.) Reim
pusilla Grun.
tumida (Breb. ex Kutz.) V.H.
Fragilaria brevistriata Grun.
brevistriata v. *inflata* (Pant.) Hust.
capucina Desm.
crotonensis Kitton
Gomphonema affine v. *insigne* (Greg.) Andrews
angustatum (Kutz.) Rabh.
intricatum Kutz.
intricatum v. *vibrio* (Ehr.) Cl.
olivaceum (Lyngbye) Kutz.
parvulum Kutz.
subclavatum (Grun.) Grun.
Mastogloia sp. Thwaites
smithii Thwaites
smithii v. *lacustris* Grun.
Melosira varians Ag.
Navicula sp. Bory
cincta (Ehr.) Kutz.
halophila f. *tenuirostris* Hust.
radiosa Kutz.
radiosa v. *tenella* (Breb.) Grun.
Nitzschia sp. Hassall
acicularis W. Sm.
amphibia Grun.
denticula Grun.
filiformis (W. Sm.) Hust.
gracilis Hantzsch
palea (Kutz.) W. Sm.
sublinearis Hust.
subrostrata Hust.
Rhoicosphenia curvata (Kutz.) Grun.

Appendix B continued.

Rhopalodia gibba (Ehr.) O. Mull.
gibba v. *ventricosa* (Kutz.) H. & M. Perag.
Synedra sp. Ehr.
acus Kutz.
acus v. *radians* (Kutz.) Hust.
amphicephala Kutz.
nana Meister
radians Kutz.
tenera W. Sm.
ulna (Nitzsch) Ehr.
ulna v. *subaequalis* Grun.

CHLOROPHYTA

Cladophora sp. Kuetzing
Chlamydomonas sp. Ehr.
Mougeotia sp. Ag.
Oedogonium sp. Link
Oocystis sp. Naegeli
gigas Archer
Platydorina caudata Kofoid
Planctonema lauterborinii Schmidle
Scenedesmus abundans (Kirch) Chodat
quadricauda (Turp.) Breb.
Sphaerocystis schroeteri Chodat
Spirogyra sp. Link
Stigeoclonium sp. Kuetzing
Ulothrix sp. Kuetzing

CYANOPHYTA

Anabaena sp. Borg
Lyngbya sp. Ag.
aestuarii (Mert.) Liebmann
major Menegh.
perelegans Lemm.
Oscillatoria sp. Vaucher
amphibia Ag.
tenuis Ag.
Phormidium sp. Kuetzing
angustissimum W. et G.S. West
favosum (Bory) Gomont
tenue (Menegh.) Gomont
Spirulina major Kuetzing

PYRROPHYTA

Peridinium cunningtonii (Lemm.) Lemm.